Ontario

Ontario Geological Survey
Open File Report 6070

Summary of Field Work and Other Activities 2001

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ONTARIO GEOLOGICAL SURVEY

Open File Report 6070

Summary of Field Work and Other Activities 2001

edited by

C.L. Baker, R.I. Kelly and J.R. Parker

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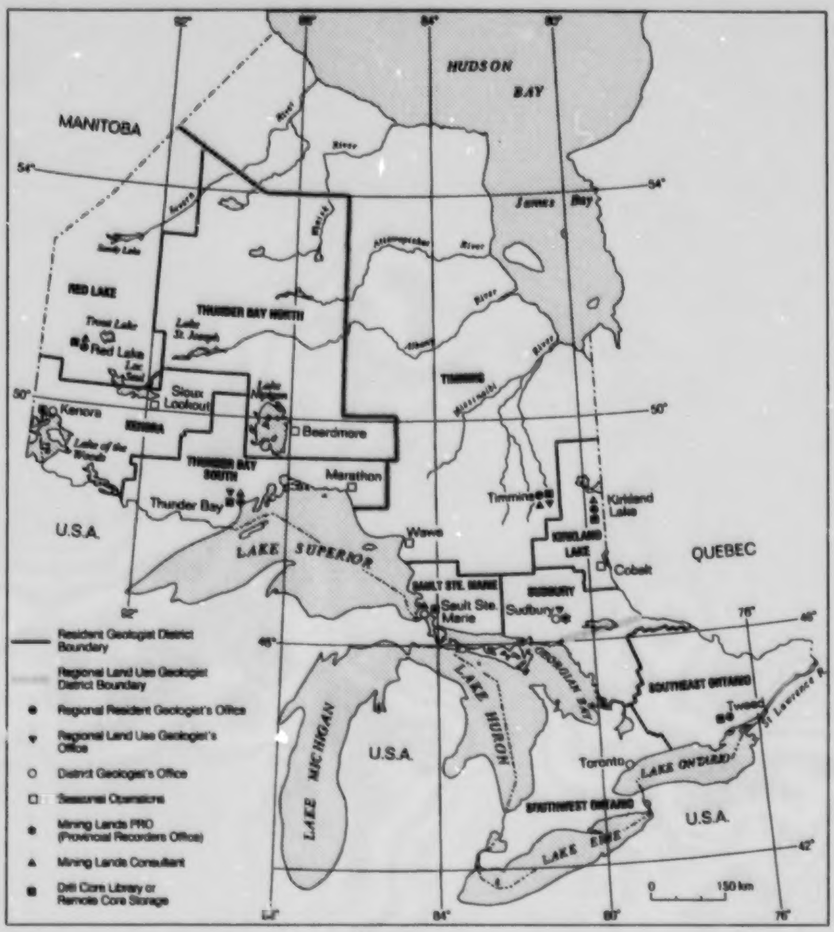
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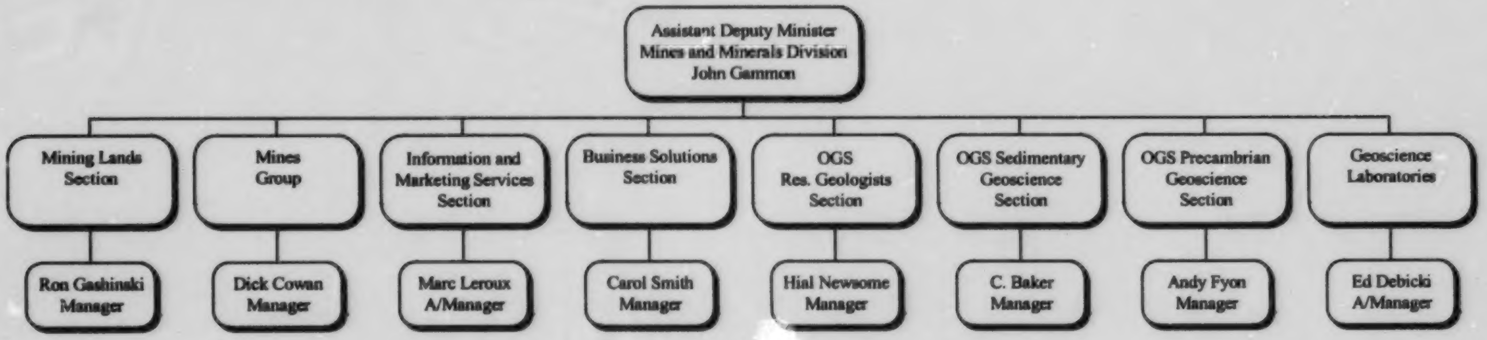
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1. Precambrian Geoscience Section – Program Overview

J.A. Fyon[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

GOAL AND RESPONSIBILITY OF THE PRECAMBRIAN GEOSCIENCE SECTION

The goal of Precambrian Geoscience Section (PGS) is to improve the understanding of the Precambrian geology of Ontario and mineral deposit settings and to convey this knowledge to clients through multi-year, multidisciplinary studies to address critical geological problems, in key geographic areas.

PGS is responsible for

- mapping of Ontario's Precambrian bedrock and understanding of various mineral deposit settings
- regional gravity, magnetic and electromagnetic geophysical data and derivative products in support of the bedrock mapping program

PROGRAM DIRECTION – STRATEGIC THRUSTS

Core Bedrock Mapping and Geophysics Program

The PGS program is organized into 4 technical or administrative strategic thrusts (Table 1.1):

- understand the geology and metallogeny of high mineral potential areas in the Superior, Southern, and Grenville provinces
- understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or deposits types currently of interest to the mineral exploration industry (e.g., potential diamond-bearing rocks, gold mineralization, rare-element and/or petalite-bearing pegmatites, platinum group element mineralization, and volcanic-associated massive sulphide mineralization)
- implement program support processes and instruments to address and refine the human resource strategy, digital data standards, program management practices, and measurement of program results
- provide liaison role, representation, or support on behalf of the Mines and Minerals Division, the OGS, and PGS on committees, advisory boards, or program-related meetings

These strategic thrusts are addressed through a series of initiatives, built upon one or more projects (Parker, this volume). The purpose of the strategic thrusts is to focus the skilled staff and resources in key geological areas to address the priorities and needs of the initiative.

To complement existing PGS staff skills and capacity, the PGS program is complemented by a series of collaborative projects, or "partnerships", with universities, other governments, and industry (*see also* Parker, this volume, Table 2.2).

Table 1.1. Strategic thrusts of the Precambrian Geoscience Section: 2000 to 2001 and beyond.

STRATEGIC THRUST	OBJECTIVES	KEY INITIATIVES
Core Bedrock Mapping and Geophysics Program		
Understand the geology and metallogeny of high mineral potential in the Superior, Southern, and Grenville provinces	a) Improve understanding of geology and mineral potential of key geographic areas that have not been mapped recently or that are inferred to contain important geological relationships, through systematic mapping and compilation at scales of 1:20 000, 1:50 000 and 1:100 000 b) Improve understanding of distribution of old and young crust that influence metallogenic patterns in western Superior Province c) Document the setting of, and controls on, platinum-palladium mineralization related to Proterozoic rocks d) Compile and interpret government and private sector regional airborne geophysics to enhance understanding of bedrock geology and mineral potential of the a) exposed Sachigo Subprovince; b) Proterozoic substrate to Hudson Bay Lowland; and Archean substrate to James Bay Lowland	Western Superior Province: NATMAP, Lithoprobe Western Superior Province: NATMAP Partnership projects with Geological Survey of Canada Abitibi Bedrock Initiative Sudbury Metallogeny Targeted Geoscience Initiative
Understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or deposits types currently of interest to the mineral exploration industry (e.g., potential diamond-bearing rocks, gold mineralization, rare-element and/or petalite-bearing pegmatites, platinum-group element mineralization (PGE) and volcanic-associated massive sulphide mineralization (VMS))	a) Improve understanding of, and mineral potential for, diamonds b) Improve understanding of, and mineral potential for, volcanic-associated, base-metal mineralization by documentation of the distribution of FII- to FIII-type felsic metavolcanic rocks across the Superior Province c) Improve understanding of, and mineral potential for, fertile peraluminous granites and related rare-element and industrial mineral (e.g., petalite) pegmatite mineralization d) Improve understanding of, and mineral potential for, magmatic Ni-Cu-PGE mineralization associated with mafic to ultramafic intrusions and komatiitic flows e) Improve understanding of geological history and metallogeny of Grenville Province, Grenville Front, and Southern Province f) Improve understanding of geology and controls on magmatic Ni-Cu-PGE mineralization in the Sudbury Igneous Complex, Nipissing mafic intrusions, and Early Proterozoic mafic intrusions g) Update and maintain geochronology database	Base program and collaborative projects, supplemented by Operation Treasure Hunt Sudbury Metallogeny Targeted Geoscience Initiative
Implement program support practices and instruments to address and refine the human resource strategy, digital data standards and program management practices	a) Complete the design and documentation of the digital mapping tools, standards, and documentation b) Continue the implementation of program planning, project management, human resource plans, and impact tracking practices, processes, tools, and databases	Core program and specific projects
Provide liaison role, representation, or support on behalf of the Mines and Minerals Division, the OGS, and PGS on committees, boards, meetings, or program needs	a) Provide executive assistant support for OGS Advisory Board and its Technical Committee b) Provide support for planning sessions involving regional client associations c) Committee of Provincial Geologists d) National Geological Surveys Committee e) Board of Directors of Mineral Exploration Research Centre, Laurentian University f) Vice-President, Canadian Exploration Geophysical Society (KEGS) g) Commissioner, North American Commission on Stratigraphic Nomenclature h) Precambrian-at-Large Representative, Joint Technical Program Committee, Geological Society of America	

Table 1.1. Continued

STRATEGIC THRUST	OBJECTIVES	STATUS
Add-on Geoscience Projects—Operation Treasure Hunt		
Contract and project management of airborne geophysical projects	a) Overall project management b) Procure proprietary airborne geophysical data c) Provide and supervise QA/QC inspection services of airborne geophysical data	Service provided by Paterson, Grant & Watson Limited; Stephen Reford is OTH Geophysicist
Procure existing airborne geophysical data	a) Acquire existing proprietary data b) Disseminate acquired data to clients in client-desired formats	Purchased about 122 000 line kilometres of proprietary airborne geophysical data in March and April 2001 (Reford et al., this volume)
Fly new airborne geophysical surveys over areas having mineral potential	Acquire new time domain electromagnetic, magnetic, and gamma-ray spectrometric data over Dryden–Ignace area and Fort Hope greenstone belt	Completed Stormy Lake airborne survey and Fort Hope survey is underway (Reford et al., this volume)
Determine physical rock properties on surface rock samples collected from the Kirkland Lake and Matheson airborne geophysical survey areas, Abitibi greenstone belt	Partnership with McMaster University	(Deschamps and Morris, this volume)
Precambrian bedrock compilation	a) Conducted over central Superior Province from Sudbury to Lake Nipigon area b) Complements on-going Grenville, Abitibi, and western Superior Province mapping and compilation efforts	(Johns, this volume)
Add-on Geoscience Project—Ontario Mineral Exploration Technology Program		
Administrative partnership with Mineral Exploration Research Centre, Laurentian University	a) Techniques to find mineral resources in bedrock beneath conductive or thick overburden. These conditions are common throughout Northern Ontario b) Methods to "see" through the Paleozoic rocks to explore for mineral resources, including diamonds, in the underlying Precambrian rock of the Hudson Bay and James Bay lowlands c) Effective ways to utilize Ontario's Quaternary geology to explore for mineral resources buried in the bedrock	Delivery by OMET Program Office, Mineral Exploration Research Centre, Laurentian University (Debicki and Fyon, this volume)

Provincially Significant Mineral Potential Project

In the spring 2000, approximately 6 PGS staff were assigned to prepare bedrock geology themes as part of the Provincially Significant Mineral Potential (PSMP) project. The staff assignment reflects the importance of this project to help ensure that technical data are available with which to make informed land-use decisions. The PGS contribution was completed in April 2001, with the completion of digital, geo-referenced Precambrian bedrock themes. Given the urgency of providing these themes to PSMP project, the themes were not prepared as hardcopy maps and are not intended to be published in the short term.

Geoscience Projects

During fiscal year 2001 to 2002, the PGS supported 66 geoscience projects (Parker, this volume). Some of these were collaborative or partnership projects (Parker, this volume).

PROJECT PLANNING, MANAGEMENT, AND CONSULTATION PROCESS

To plan and deliver 66 active geoscience projects, delivered by core staff and in collaboration with our partners, PGS management and staff continued to refine the planning and project management processes and practices. Information required to describe projects, monitor and adjust progress, and assess their impact on the minerals industry is collected and analyzed to assess if program goals are met (e.g., Churchill and Fyon 1999; Churchill et al. 2000; Churchill, Fyon and Baker, this volume).

To formulate and discuss project plans for summer of 2001 and to begin development of summer 2002 project plans, PGS staff were involved in several consultations:

1. March 2001: OGS Technical Committee
2. May, June, and September 2001: several project scoping meetings with industry, Mineral Exploration Research Centre (Laurentian University), and Geological Survey of Canada
3. April 2001: Eagle Lake First Nation community and Wabigoon First Nation community to discuss preliminary results of the Operation Treasure Hunt Stormy Lake airborne geophysical survey
4. August and September 2001: Kasabonika Lake First Nation to discuss possible geoscientific projects for the far north, attend a prospectors meeting, conduct property visit and gather samples
5. August 2001: Eabametoong Lake First Nation to hold a community-based open house to demonstrate the aircraft used in the Operation Treasure Hunt Fort Hope airborne geophysical survey, typical geophysical results, and a display illustrating the degree to which geology impacts our daily lives

ADD-ON PROGRAMS

PGS staff collaborated with other OGS staff to formulate and deliver 3 significant add-on geoscience programs:

- Phoenix bedrock mapping project (Hart et al., this volume)
- Operation Treasure Hunt (Breaks, Selway and Tindle, this volume; Vaillancourt et al., this volume; Deschamps and Morris, this volume; Reford et al., this volume; Johns, this volume)
- Ontario Mineral Exploration Technologies Program (Debicki and Fyon, this volume)

Phoenix Bedrock Mapping Project

PGS partnered with Lake Nipigon Heritage Authority to conduct a bedrock mapping project in the Beardmore area. The goal of the Phoenix bedrock mapping project is to increase mineral exploration investment in the area by creating new geological maps for the townships of Sandra, Dorothea, Kitto, Eva and Summers (Hart et al., this volume; Parker, this volume). The Phoenix project is funded ($384 295) by an Industry Canada allocation to the Lake Nipigon Heritage Authority, which, in turn, subcontracted PGS to deliver the project. The federal funds flow through GEO Enterprises, the business development arm of the Mines and Minerals Division, Ministry of Northern Development and Mines. The OGS will deliver and manage the bedrock mapping project to maximize access to confidential private sector information; to apply the objective OGS technical mapping standards; to help increase the public awareness about the geology of the area and its mineral potential; and to increase the geoscience data inventory describing Ontario through objective OGS published maps and reports. T.R. Hart is the project geologist (Hart et al., this volume).

Operation Treasure Hunt

The Operation Treasure Hunt (OTH) geoscience initiative began in April 1999. The goal of OTH is to generate new exploration targets in industry priority areas, while contributing new geoscience information to enhance the understanding of the Precambrian geology of Ontario and the settings of mineral deposits (Fyon et al., this volume). During the 2000 to 2001 fiscal year, PGS staff co-ordinate or deliver the following OTH projects (Fyon et al., this volume):

- airborne geophysical survey program (Reford et al., this volume)
  - flying of new airborne geophysical surveys
  - acquisition of existing proprietary airborne geophysical surveys
  - preparation of an atlas and database to illustrate the location, ownership, and technical specifications of some airborne geophysical surveys over Ontario
- physical rock properties project (Deschamps and Morris, this volume)
- 1:250 000 scale bedrock geology map compilation (Johns, this volume)
- compilation and understanding of platinum group element mineralization and mafic to ultramafic intrusions across Ontario (Vaillancourt et al., this volume) in collaboration with the Mineral Exploration Research Centre (MERC, Laurentian University) and the Mineral Resources Division of the Geological Survey of Canada
- compilation and understanding of fertile peraluminous granites and related rare-element pegmatite mineralization in Ontario (Breaks, Selway and Tindle, this volume)

Ontario Mineral Exploration Technology Program

In March 2001, an administrative agreement was signed between the Ministry of Northern Development and Mines and Laurentian University. Under the agreement, the Mineral Exploration Research Centre (Laurentian University) will administer the Ontario Mineral Exploration Technology (OMET) Program. The goal of OMET is to lever the Government's investment in innovative, collaborative, multidisciplinary technology and methods research projects to provide solutions to technical problems facing the mineral exploration industry in Ontario (Debicki and Fyon, this volume).

The Ontario Government committed new funds of $8 million, over 4 years, beginning in the fiscal year 2000 to 2001.

OMET will focus research on 3 themes:

- best techniques to find mineral resources in bedrock beneath conductive or thick cover
- best methods to "see" through the Paleozoic rocks to explore for mineral resources, including diamonds, in the underlying Precambrian rock of the Hudson Bay and James Bay lowlands
- effective ways to utilize Ontario's Quaternary geology to explore for mineral resources buried in the bedrock

The types of research projects that will be considered include

- projects that develop a concept
- projects that prove a concept
- projects that demonstrate a concept or principle.

Other project types may be considered. Collaborative projects with the potential to attract matching funds are desirable, but not obligatory. Additional details about the OMET program are available at the OMET web page http://www.omet.laurentian.ca or by request at OMET@nickel.laurentian.ca.

INTER-JURISDICTIONAL AND COMMITTEE REPRESENTATION

During the 2000 to 2001 fiscal year, PGS staff represent the Ontario Geological Survey on several inter-jurisdictional committees and associations, including

1. Committee of Provincial Geologists
2. National Geological Surveys Committee
3. Mineral Exploration Research Centre, Laurentian University, Board of Directors
4. Lithoprobe Western Superior Transect liaison
5. Vice-President of the Canadian Exploration Geophysical Society (KEGS)
6. Chair, GIS Division, Geological Association of Canada
7. Executive of Sudbury Geological Discussion Group
8. Commissioner, North American Commission on Stratigraphic Nomenclature (until November 2002)
9. Precambrian-at-Large Representative, Joint Technical Program Committee, Geological Society of America
10. Adjunct professor at Carleton University, University of Ottawa, or Laurentian University.

ONTARIO GEOLOGICAL SURVEY ADVISORY BOARD

PGS provides executive support to the OGS Advisory Board and its geoscience Technical Committee. During the past year, the OGS Advisory Board and its Technical Committee met several times.

1. December 2000: OGS Advisory Board met with OGS to review key OGS initiatives and develop recommendations to be presented to the Minister of Northern Development and Mines.
2. February and March 2001: OGS Technical Committee met with OGS to review OGS mapping program and Operation Treasure Hunt.
3. November 2001: OGS Advisory Board met with the OGS, Minister Newman, and Deputy Minister Clark.

CHANGES TO THE SECTION

On March 31, 2001, Dr. R.P. Sage retired from the Ontario Geological Survey following over 30 years of service.

B. Berdusco resigned his position as applicationist for the PGS to take a position with the Business Solutions Section of the Mines and Minerals Division.

J.R. Parker assumed the duties of Acting Manager, Bedrock Mapping and Geophysics, as part of a training and development opportunity since December 2000.

L.A.F. Hall joined the PGS as the project geologist for a one-year project to map the complex bedrock geology west of Timmins in Carscallen and Denton townships (Hall, this volume).

C.A. Macdonald joined the PGS to participate on a one-year Operation Treasure Hunt project to study and inventory platinum group element (PGE) mineralization and mafic to ultramafic intrusions in Ontario under the leadership of C. Vaillancourt (Vaillancourt et al., this volume).

J.B. Selway joined the PGS to participate on a one-year Operation Treasure Hunt project to study fertile peraluminous granites and related rare-element pegmatite mineralization in Ontario under the leadership of F.W. Breaks (Breaks, Selway and Tindle, this volume).

T.R. Hart assumed a one-year contract to deliver the Phoenix bedrock mapping project in the Beardmore area (Hart et al., this volume). The Phoenix bedrock mapping is funded by an allocation from FedNor (Industry Canada Initiative) to the Lake Nipigon Heritage Authority, which, in turn, funded the Ontario Geological Survey.

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Churchill, L.L., Roque, J., Baker, C.L. and Fyon, J.A. 2000. Preliminary impact analysis of Operation Treasure Hunt surveys; *in* Summary of Field Work and Other Activities 2000, Ontario Geological Survey, Open File Report 6032, p.48-1 to 48-10.

2. Precambrian Geoscience Section – Project Overview

J.R. Parker[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The fundamental core functions of Precambrian Geoscience Section (PGS) projects are to

1. provide geoscience maps, reports, data, technical talks and posters, new concepts and ideas and client consultations; and
2. provide regional airborne magnetic and electromagnetic geophysical data, derivative products, and concepts and ideas based on those geophysical data to support the bedrock mapping program.

In 2001, the PGS produced 27 preliminary maps, 12 open file reports, 4 miscellaneous data releases, 3 final maps and 1 report. Approximately 25 technical talks and 37 posters were presented at various geoscience forums throughout the year.

The program direction and strategic thrusts (Fyon, this volume) of the PGS address the mission statement and core business of the Ministry of Northern Development and Mines. Strategic thrusts are achieved through a variety of initiatives that are built upon one or more projects (Table 2.1). Therefore, project development, selection, planning and implementation are based on the strategic thrusts and initiatives in order to achieve alignment of individual projects with Ministry priorities.

The PGS presently has 32 active core projects that include 10 collaborative agreements with the Geological Survey of Canada (GSC) (*see* Table 2.1). The PGS is also involved in 24 active collaborative project agreements (Table 2.2), in various stages of completion, with a variety of partners. Ten projects are included in add-on programs such as the Operation Treasure Hunt initiative and the Phoenix Bedrock Mapping project (*see* Table 2.1). In all, the PGS supported 66 geoscience projects during the 2001 to 2002 fiscal year.

PRECAMBRIAN GEOSCIENCE SECTION INITIATIVES

PGS initiatives are based on geographic or functional groupings and are made up of 1) team initiatives (i.e., Abitibi initiative) consisting of individual projects that are designed to meet an overall goal; 2) inter-jurisdictional team initiatives, such as Western Superior NATMAP, that consist of individual and joint OGS and GSC projects that are also designed to meet an overall goal or objective; 3) individual, focussed projects. The major initiatives of the PGS are subdivided into 5 broad categories outlined below and in Table 2.1.

Table 2.1. Initiatives and projects of the Precambrian Geoscience Section, 2000 to 2001.

STRATEGIC THRUST	INITIATIVE	PROJECT
Core Bedrock Mapping and Geophysics Program		
Understand the geology and metallogeny of high mineral potential in the Superior, Southern, and Grenville provinces	Collaborative projects with Geological Survey of Canada (GSC): Western Superior NATMAP and Lithoprobe Initiatives	a) Structural/stratigraphic and metallogenic synthesis Red Lake greenstone belt b) Geology of the east Sachigo Subprovince c) Geology of the south-central Wabigoon Subprovince d) Geology of the east Wabigoon Subprovince e) Regional metallogeny of northwest Superior Province
	Collaborative projects with Geological Survey of Canada (GSC): Sudbury Targeted Geoscience Initiative (TGI)	f) Improve understanding of geology and controls on mineralization of nickel-copper-PGE mineralization in the Sudbury Igneous Complex (SIC)
	Collaborative projects with Geological Survey of Canada (GSC): Far North Initiative	g) Reprocessing of ODM/GSC geophysics of exposed Archean h) Reprocessing of ODM/GSC geophysics of Archean substrate i) Reprocessing of ODM/GSC geophysics of Proterozoic substrate
	Metallogeny of Northwest Ontario	j) Geology of the Wabigoon Lake area
	Proterozoic Initiative	k) Geology of the Mazinaw and Palmerston Lake area l) Geology of the Puzzle Lake area
	Abitibi Initiative	m) Geological compilation of Swayze and Matachewan: Abitibi greenstone belt n) Regional mapping in the Matachewan area o) Geology of Shining Tree area (Kemp, Burrows and Mond townships) p) Bedrock mapping in the Timmins West area (Carscallen and Denton townships)
Understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or deposits types currently of interest to the mineral exploration industry (e.g., potential diamond-bearing rocks, gold mineralization, rare-element and/or petalite-bearing pegmatites, platinum group element mineralization (PGE) and volcanic-associated massive sulphide mineralization (VMS))	Provincial-scale diamond assessment	q) Kimberlite, base metal and gold indicator minerals study in surficial materials, northern Superior Province
	Provincial-scale metallogenic inventory	r) Distribution of FII- to FIII-type, potentially VMS-productive felsic metavolcanic rocks s) Characteristics of mineralized intermediate of felsic plutonic systems t) Update and maintain geochronology database
	Provincial-scale pegmatite mineralization (supported by Operation Treasure Hunt)	u) Fertile peraluminous granites and related rare-element pegmatite mineralization in Ontario
	Documentation of magmatic nickel-copper-PGE metallogeny in Ontario (supported by OTH and in collaboration with the GSC and MERC–Laurentian University)	v) Platinum-group element inventory in mafic to ultramafic intrusions in Ontario
	Documentation of magmatic nickel-copper-PGE metallogeny in Ontario: Proterozoic Initiative	w) Geology and mineral potential of mafic intrusions in Flett and Angus townships, Grenville Province x) Geological compilation of the Glen Afton (River Valley) area y) Geology of Dana and Crerar townships z) Geochemistry of Osler Group rocks, etc.

Table 2.1. Continued

STRATEGIC THRUST	INITIATIVE	PROJECT
Implement program support practices and instruments to address and refine the human resource strategy, digital data standards and program management practices	Support and Program Management Practices	aa) Attributed maps (Smart Maps) synoptic mapping: Abitibi Subprovince and elsewhere. bb) Digital map standards throughout Ontario cc) Geophysics integration with bedrock mapping dd) Learning plan for PGS-administrative project ee) Impact analysis of geoscience projects
Add-On Geoscience Projects – Operation Treasure Hunt (OTH)		
Contract and project management of airborne geophysical projects; procure existing airborne geophysical data; fly new airborne geophysical surveys over areas having mineral potential; advance innovative ways to interpret OTH airborne geophysical data	OTH Geophysics	a) Operation Treasure Hunt General Geophysical Contract Management b) Airborne Geophysical Project Survey Management (Paterson, Grant and Watson Limited managed) c) QA/QC inspection function (Paterson, Grant and Watson Limited managed) d) Stormy Lake Airborne Geophysical Survey e) Fort Hope Airborne Geophysical Survey f) Mineral Production Model (GSC managed) g) Evaluation of geophysical interpretation approaches for geological mapping and mineral exploration in greenstone belts (Partnership Project: GSC managed)
Determine physical rock properties from surface rock samples collected from the Kirkland Lake and Matheson airborne geophysical survey areas, Abitibi greenstone belt	OTH Rock Properties (partnership with McMaster University)	h) Physical Rock Properties Study
Precambrian geological compilation	OTH Geological Compilation Maps	i) 1:250 000 scale geological compilation map series
Add-On Geoscience Projects – Phoenix Bedrock Mapping Project		
Understand the geology and metallogeny of high mineral potential in the Superior, Southern, and Grenville provinces	Phoenix–Beardmore Initiative (funded by a grant from FEDNOR, an Industry Canada Initiative, to Lake Nipigon Heritage Authority)	a) Phoenix Bedrock Mapping Project: 1:20 000 and 1:50 000 scale mapping of Kitto, Eva, Summers, Dorothea and Sandra townships, Beardmore area

Table 2.2. Initiatives and collaborative project agreements of the Precambrian Geoscience Section, 2000 to 2001.

INITIATIVE	PROJECT NAME	COLLABORATION PARTNER(S)
Abitibi	Holloway Township structural geology	University of Ottawa, Battle Mountain Gold, Barrick Gold Corp.
	Matheson syenite project, Highway 101 East	University of Ottawa
	Geochemistry and metallogenesis of komatiites in Ontario: compilation project	Mineral Exploration Research Centre, Laurentian University
	Physical volcanology of komatiites in Ontario	Mineral Exploration Research Centre, Laurentian University

Table 2.2. Continued

INITIATIVE	PROJECT NAME	COLLABORATION PARTNER(S)
Abitibi	Geology, volcanology, lithogeochemistry and alteration associated with base metal mineralization in the Big Four Lake area, Shining Tree	University of Ottawa
	Kenogamissi batholith structural emplacement	University of Ottawa
	Geochemistry and tectonic evolution of Shining Tree area, southern Abitibi greenstone belt	Portsmouth University
	GIS and Remote Sensing Applications in the identification of the location and spatial association of kimberlite in the Lake Timiskaming structure	Laurentian University
	Timmins gravity survey	Placer Dome (CLA) Ltd., Geomatics Canada, Explorers Alliance Corp.
	Kapuskasing–Chapleau aeromagnetic survey	FEDNOR, GSC, Sial Geosciences, Goldak Exploration, Scintrex Airborne Systems and Surveys
Documentation of magmatic nickel-copper-PGE metallogeny in Ontario	Geology, stratigraphy, chemostratigraphy, and ore mineralogy of the River Valley intrusion	Mineral Exploration Research Centre, Laurentian University
	Geology, stratigraphy, chemostratigraphy, ore mineralogy and metallogeny of Entwine Lake intrusion, Wabigoon Subprovince	Mineral Exploration Research Centre, Laurentian University
Metallogeny of Northwest Ontario	Hyperspectral survey, Red Lake greenstone belt	Canadian Centre for Remote Sensing
Collaborative projects with Geological Survey of Canada (GSC): Sudbury Targeted Geoscience Initiative (TGI)	Structural analysis of the western Sudbury basin, Trill, Drury, Fairbank and Denison townships	University of Ottawa
Provincial-scale pegmatite mineralization	Time scales of formation of rare-metal pegmatites in Archean rocks	Open University
Western Superior Lithoprobe	Structural controls on shear-hosted gold occurrences in the Beardmore–Geraldton Belt at the Quetico–Wabigoon subprovincial boundary	Laurentian University
	Sm/Nd isotope study: correlation between central and east Wabigoon Subprovince	Geological Survey of Canada
	Western Superior Lithoprobe Transects: reflection seismic transect routes	Geological Survey of Canada and various universities
Western Superior NATMAP	Volcanology and VMS-related alteration and mineralization of Marshall Lake, Archean felsic volcanic centre: eastern Wabigoon Subprovince	Laurentian University
	Western Wabigoon compilation	Geological Survey of Canada
	East Uchi compilation	Geological Survey of Canada
	North-central Wabigoon compilation	Geological Survey of Canada
Collaborative projects with GSC	Canadian Geoscience Knowledge Network	Geological Survey of Canada
Collaborative projects with GSC	Mineral potential assessment through modelling geophysical data	Geological Survey of Canada – Spatial Data Analysis Laboratory

1. Initiatives that involve collaborative project agreements with the Geological Survey of Canada
    - Western Superior NATMAP and Lithoprobe mainly focussed in north and northwest Ontario
    - Targeted Geoscience Initiative focussed on the Sudbury Igneous Complex (SIC)
    - The Far North Initiative in the Hudson and James Bay lowlands

2. Initiatives involving provincial-scale metallogenic compilation and inventory studies
    - Documentation of pegmatite-hosted mineralization (supported by Operation Treasure Hunt)
    - Documentation of magmatic nickel-copper-platinum group elements (PGE) metallogeny in Ontario that includes projects such as the PGE mineralization and mafic to ultramafic intrusion compilation and inventory (supported by Operation Treasure Hunt with collaborative project agreements between OGS and the Mineral Exploration Research Centre (MERC, Laurentian University) and GSC, respectively)
    - Diamond assessment
    - Inventories of various tectonic settings relevant to mineral exploration

3. Initiatives based on geographic area
    - The Abitibi Initiative
    - Metallogeny of northwest Ontario
    - The Proterozoic Initiative

4. Initiatives involving program support practices and instruments to address and refine human resource strategies, digital data standards and program management practices
    - Support and program management practices
    - Project and results management
    - Geophysics integration with bedrock mapping

5. Initiatives based on add-on programs such as Operation Treasure Hunt (OTH)
    - OTH airborne geophysics
    - OTH physical rock properties
    - OTH geological compilation maps
    - Phoenix–Beardmore Initiative (funded by FEDNOR, an Industry Canada Initiative, through the Lake Nipigon Heritage Authority).

Collaborative Projects with the Geological Survey of Canada

Field work for the Western Superior NATMAP initiative was completed in 2000. In 2001, the PGS completed two 1:250 000 bedrock compilation maps for release in December 2001: 1) the East Wabigoon sheet encompassing the Onaman–Tashota greenstone belt; and 2) the South-Central Wabigoon sheet encompassing the Atikokan and Lumby Lake areas. A 1:250 000 map sheet for the east Sachigo Subprovince is scheduled for release in the spring of 2002. The PGS is also responsible for completing a series of 6 metallogenic compilation maps building upon the bedrock compilation maps. The Geological Survey of Canada (GSC) is responsible for delivering the Western and North-Central Wabigoon bedrock maps for release in December, 2001, as well as the East Uchi map sheet in March, 2002. The maps and other geoscience data will also be released on CD-ROM in 2002 as well as a 1: 1 000 000 scale map of the western Superior Province.

As part of the Western Superior NATMAP Initiative, staff from the GSC, PGS and the OGS Red Lake Resident Geologist Program organized a one-day NATMAP workshop, in June, 2001 in Red Lake, to review results of recent mapping; structural, stratigraphic and tectonic interpretations; and alteration studies and metallogenic work in the Red Lake greenstone belt. The workshop was attended by about 50 geologists and prospectors from the mineral industry.

One partnership project with Laurentian University continued under the Western Superior Lithoprobe Initiative to study structural controls on shear zone-hosted gold mineralization in the Beardmore–Geraldton Belt at the Quetico–Wabigoon subprovince boundary (Dewolfe, this volume). This two-year project is supported under an Ontario Geological Survey–Laurentian University Graduate Mapping School Agreement. On-going interpretation of the Lithoprobe reflection seismic transect routes across the western Superior Province continued through 2001, as well as a Sm/Nd isotope study to assist in the correlation between the central and eastern portions of the Wabigoon Subprovince.

The Sudbury Targeted Geoscience Initiative (TGI) is a three-year program (2000 to 2003) designed to gain a better understanding of the setting and processes involved in forming the large nickel-copper-PGE deposits of the Sudbury Igneous Complex (Ames et al., this volume). The initiative consists of 4 collaborative projects that include the Geological Survey of Canada, the Ontario Geological Survey, mineral industry and several universities. A one-day field trip was offered in August, 2001, to the mineral industry to review the initial work of the 4 projects. One of these projects is an investigation of the lithological and structural controls on mineralization in the Sudbury Igneous Complex and in its immediate footwall (Dubois and Benn, this volume). This two-year project supported under an Ontario Geological Survey–University of Ottawa Collaborative Project Agreement, will involve extensive mapping in contiguous parts of Trill, Drury, Fairbank and Denison townships in the southwest part of the SIC.

Provincial-Scale Metallogenic Compilation and Inventory Studies

There has been a significant increase in exploration interest for rare-element mineral deposits in Ontario during the past year. This interest is a result of the surging price of tantalum, which, in 2000, was the top-performing metal, the price of which increased 420%. The PGS expanded an existing rare-element pegmatite characterization project. The result is an ambitious project to compile, document and study fertile peraluminous granites and related rare-element pegmatites across Ontario (Breaks, Selway and Tindle, this volume). The purpose of this project, supported by the Operation Treasure Hunt initiative, is the preparation of a comprehensive field, chemical, mineralogical and geochronological database for fertile granites and associated rare-element pegmatites for the entire Superior Province of Ontario. Field work in 2001 focussed on northwestern Ontario augmented by a small amount of work in northeastern Ontario. Several new and exciting exploration targets were identified (Breaks, Selway and Tindle, this volume).

Another ambitious project, supported by Operation Treasure Hunt, was initiated to determine the potential for PGE mineralization in mafic to ultramafic intrusions across Ontario (Vaillancourt et al., this volume). The project is a collaborative effort between the PGS, the Mineral Exploration Research Centre (MERC, Laurentian University) and the Mineral Resources Division of the GSC. This project is part of the initiative to document magmatic nickel-copper-PGE metallogeny in Ontario as well as other projects such as 1) mapping mafic to ultramafic intrusions in Flett and Angus Townships, Grenville Province (Easton, this volume); and 2) a study of the geology, stratigraphy, chemostratigraphy, ore mineralogy and metallogeny of the Entwine Lake intrusion, Wabigoon Subprovince (Arnold, this volume), which is also an Ontario Geological Survey–Mineral Exploration Research Centre (MERC, Laurentian University) Collaborative Project Agreement.

On-going, multi-year, province-scale projects that fall under the initiative to create inventories of various tectonic settings relevant to mineral exploration are 1) the documentation and distribution of FII- and FIII-type, potentially volcanogenic massive sulphide deposit (VMS)-productive felsic metavolcanic rocks; 2) characteristics of mineralized intermediate to felsic plutonic systems; and 3) update and maintain the geochronology database for Ontario.

R.P. Sage, project leader for the province-scale diamond assessment project, retired in March 2001. However, D. Stone continued an on-going kimberlite, base metal and gold indicator minerals study in the northern Superior Province (Stone 2001).

Initiatives Based on Geographic Area

The Abitibi initiative includes 4 core, multi-year, mapping projects (*see* Table 2.1), including the 1:100 000 scale Abitibi compilation in the Swayze and Matachewan areas, as well as 10 collaborative project agreements (*see* Table 2.2) (Ayer and Trowell, this volume).

The metallogeny of northwest Ontario initiative currently includes 2 projects 1) geological mapping in the Dryden–Wabigoon area (Beakhouse, this volume); and 2) a hyperspectral survey in the Red Lake greenstone belt for which the OGS partnered with the Canada Centre for Remote Sensing, Natural Resources Canada (Rudd, this volume).

The Proterozoic initiative includes several projects that were closed this year such as 1) completion of six 1:50 000 scale geological maps in the Kaladar–Barry's Bay area of the Grenville Province (Easton 2001a-f); 2) geology and mineral potential of the Puzzle Lake area (Easton 2001g); 3) geology of Dana and Crerar townships (Easton and Hrominchuk 2001a, 2001b); and 4) a geological compilation of the Glen Afton (River Valley) area. The geochemistry of the Osler Group volcanics is a new project that was initiated this year to reanalyze more than 400 rock sample pulps in OGS archives from previous OGS mapping projects conducted in the Lake Nipigon region. The samples were collected from a variety of mafic to ultramafic intrusive rocks and metavolcanic rocks and are being analyzed for platinum group elements.

Initiatives Involving Program Support and Program Management Practices

The Project and Results Management initiative includes the analysis of economic impact of the PGS projects (Churchill, Fyon and Baker, this volume).

Beginning this year, and following the addition of a Geophysicist to the staff, potential field geophysical data was more systematically and comprehensively integrated with the bedrock mapping function. Bedrock geological interpretations will be enhanced by integration of available geophysical data sets and knowledge in the mapping area (Rudd, this volume). Geophysical data are integral to project planning and conception; in project delivery; and in the final products resulting from bedrock mapping projects. This initiative also includes the recent acquisition of 6 hand-held magnetic susceptibility meters to aid in interpreting geology on the outcrops and to begin to build a province-wide magnetic susceptibility database (Rudd, this volume). A twinning agreement, established in 1999 between the OGS and the Geological Survey of New South Wales (GSNSW), Australia, was established to enhance scientific knowledge and application and improve program delivery and impact. A recent visit to the GSNSW by OGS staff has identified the many similarities in purpose and product delivery process. The geophysical program within the GSNSW also provides an excellent model of integration with bedrock mapping. The OGS-PGS will be adapting some of the best practices of the GSNSW in upcoming bedrock mapping projects for 2002 (Rudd, this volume).

Initiatives Based on Add-On Programs

Operation Treasure Hunt (OTH) projects (*see* Table 2.1) are included under the following initiatives: 1) OTH geophysics (Reford et al., this volume; Fyon et al., this volume); 2) OTH rock properties (Deschamps and Morris, this volume) which is a partnership with McMaster University; and 3) the OTH geological compilation map project (Johns, this volume), which is led by G.W. Johns and assisted by S. McIlraith. The reader is referred to the articles list above for detailed summaries of each project.

A new add-on project for 2001 is the Phoenix Bedrock Mapping project (Fyon, this volume; Hart et al. this volume). The objective of the project is to conduct bedrock mapping at 1:20 000 and 1:50 000 scale in a large area, east of Lake Nipigon and west of Beardmore, that was burnt during a major forest fire in 1999. The fire has enhanced outcrop exposure in most of Kitto, Eva and Dorothea townships and parts of Summers and Sandra townships, providing an opportunity to collect new geoscience information. The Beardmore area has mineral resource potential for gold, volcanogenic massive sulphide mineralization and magmatic platinum group element (PGE) mineralization (Hart et al., this volume). The new geoscience information and maps that result from this project will generate interest in prospecting, mineral exploration and investment and create and/or maintain community-based jobs and opportunities for the Municipality of Greenstone and surrounding area. Bedrock mapping conducted in Kitto Township, during this project, is the first time the township has been mapped in detail.

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——— 2001d. Precambrian geology, Tichbourne area; Ontario Geological Survey, Preliminary Map, P.3442, scale 1:50 000.

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3. Project Unit 00-029. Measuring the Results of Ontario Geological Survey Projects

L.L. Churchill[1], J.A. Fyon[1] and C.L. Baker[2]

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INTRODUCTION

Over the past several years, the Ontario Geological Survey (OGS) has documented the results of its geological survey projects. Aspects of the OGS documentation and analysis are derived from the practices and theories of results based management (RBM) used by many organizations, and supplemented by OGS experiences, to reinforce the goal of results-oriented and accountable management.

The OGS has adapted standard RBM practices to objectively document credible and quantifiable impacts of the OGS geoscience program. We are conservative in our approach using only those figures that can be justifiably supported. Government accountability requires that government programs (Churchill 1998; Churchill and Fyon 1999; Churchill et al. 2000)

- demonstrate value for public investment
- link project costs to results
- effectively manage project-related information to ensure optimal program delivery to meet Government and client needs and objectives

The goal of the long-term analysis of geoscience project results is to demonstrate and quantify the degree to which the design and delivery of OGS geoscience projects are effective in meeting government and clients needs and priorities, which include (Churchill et al. 2000)

- accountability for public funds;
- retaining and attracting mineral investment to Ontario
- stimulating mineral or other resource exploration, advanced exploration and mine development
- influencing private sector minerals investment decisions in Ontario
- contributing to science and technology capacity of Ontario-based industry
- contributing to informed land-use decisions

Government geological surveys around the world are refining their management processes to document these impact and accountability matrices. In this article, we present a summary of the evolving OGS approach and our current practices.

DEFINITIONS

The following terms are used in this summary:

Result – a describable or measurable change that is derived from a cause and effect relationship (e.g., a change of staking pattern occurs following the release of a geological report)

Output – a short-term result or a deliverable produced by a project (e.g., a geological map)

Impact – long-term results (e.g., the social and economic well-being of Ontario is enhanced)

Indicator – a pointer, measurement, number, fact, opinion or perception that helps to measure the progress towards achieving the desired results.

ANALYZING RESULTS OF GOVERNMENT-FUNDED GEOLOGICAL SURVEYS: CONTEXT

Factors that Influence Investment Decisions

One of the results that the OGS tracks is private sector investment triggered by an OGS project or service. However, there are many local and global factors that the private sector considers as part of their decision to invest in a jurisdiction, including

- global commodity prices
- availability of mineral investment funds or risk capital
- public policy
- local mining act and certainty of land tenure
- land available to stake and explore
- geology of the target jurisdiction
- quality and availability of the description of the geology of that jurisdiction
- client awareness of geological documentation achieved by marketing
- timing of the public release of government-funded geological survey data
- mineral development and industry support services available in that jurisdiction

Attribution

An investment decision can seldom be attributed to a single output or factor, such as the release of a geological survey report and/or map. We recognize that it is the combination of factors, including the release of an output, such as the release of geoscience data, that trigger a result.

Approach: Ontario Geological Survey Practice to Measure Results

Within the context of the attribution issue, the OGS developed a practice to empirically and objectively quantify private sector results that are attributed to an OGS output, such as the announcement, delivery, and product release for a geological survey project. This practice requires the consistent and objective tracking of several indicators that serve as a proxy for the impact of the OGS geoscience program (Table 3.1). The OGS practice is to track the indicator, such as increased staking, that corresponds in time with the release of an output, such as a release of geoscience data. By monitoring an indicator for at least one year in advance of the output, we attempt to quantify a baseline that reflects the combination of factors prior to the release of the output. We attribute the change in the baseline, which occurs almost simultaneously with the release of the output, entirely to the output.

Table 3.1. Indicators used by the Ontario Geological Survey to measure the results of the geoscience program.

	OGS RESULT INDICATOR	OGS PRACTICE	CONSIDERATIONS
Short-Term Results			
1	Claim Activity	Number of net active claims in an area (all new claims less claims cancelled for defined timeframe)	• Quantitative measure • Net active claims portrays an accurate picture of total claim activity in an area, including both claims cancelled (negative impact) and new claims recorded (positive impact)
2	Geoscience Product Sales	Number of product sales for signature programs only, e.g., Operation Treasure Hunt Number of products for each format, e.g., hardcopy maps or digital data	• Quantitative measure • Product sales may demonstrate an immediate interest in an area, but the product itself is the legacy of the geoscience project that may be used 25 years after the project. • Many factors determine sales volume, including: – global commodity price and current commodity sought by exploration – physical access to an area • It may only take the sale of one product to one client to lever a large private sector investment. • Most jurisdictions in Canada market their products and services as the "tourist brochures" to bring investors into an area and hence keep the cost minimal.
3	Client Testimonials	Testimonials from users of the OGS geoscience products or consultation services	• Qualitative measure • Testimonials acquired from press releases, letters and personal communication • These testimonials can be undisputed with respect to attribution to OGS work as those very companies doing the work provide them. • Strive to obtain written sign-off by the author of the testimonial prior to OGS use to ensure credibility • Companies support this approach
Medium- to Long-Term Results			
4	Investment Expenditure	Dollars invested to explore or develop a property	• Quantitative measure • Confirm the investment is attributed in whole, or part, to the OGS geoscience product or service; OGS staff follow-up with clients to gather more information where attribution to the OGS is acknowledged • Report only data obtained from annual reports, press releases and personal communications • Credibility of data assured by written sign-off by the company or individual who made the investment • Confidential data is not released to public or Minister • Actual investment is often greater than reported by OGS
5	Science and Technology Advancement	Testimonials describing the link between private sector or university science and technology development and an OGS program, project, or service	

Short-Term Results: Claim Staking Activity

With the implementation of the MNDM Claims and CLAIMaps computer systems, the OGS is able to track claim activity throughout Ontario. Two study areas illustrate the results of monitoring the claim activity indicator: the Schreiber survey area and the Garden–Obonga survey area. (Figures 3.1 and 3.2).

Since February 1998, one year before the announcement of the Operation Treasure Hunt geoscience program, the number of total claims in good standing (new claims less lapsed claims) in the Schreiber survey area, increased from 1750 to 5250 following the release of results for 2 lake sediment geochemical surveys and 1 airborne geophysical survey (*see* Figure 3.1). The short-term results attributed to the release of results for the 3 OGS surveys is a 200% increase in the number of claims in good standing.

Since February 1998, one year before the announcement of the Operation Treasure Hunt geoscience program, the number of total claims in good standing in the Garden–Obonga survey area increased from 4000 to 15 000 following the release of results for the 2 lake sediment geochemical surveys and 1 airborne geophysical survey (*see* Figure 3.2). The short-term result attributed to the release of the 3 OGS surveys is a 275% increase in the number of claims in good standing.

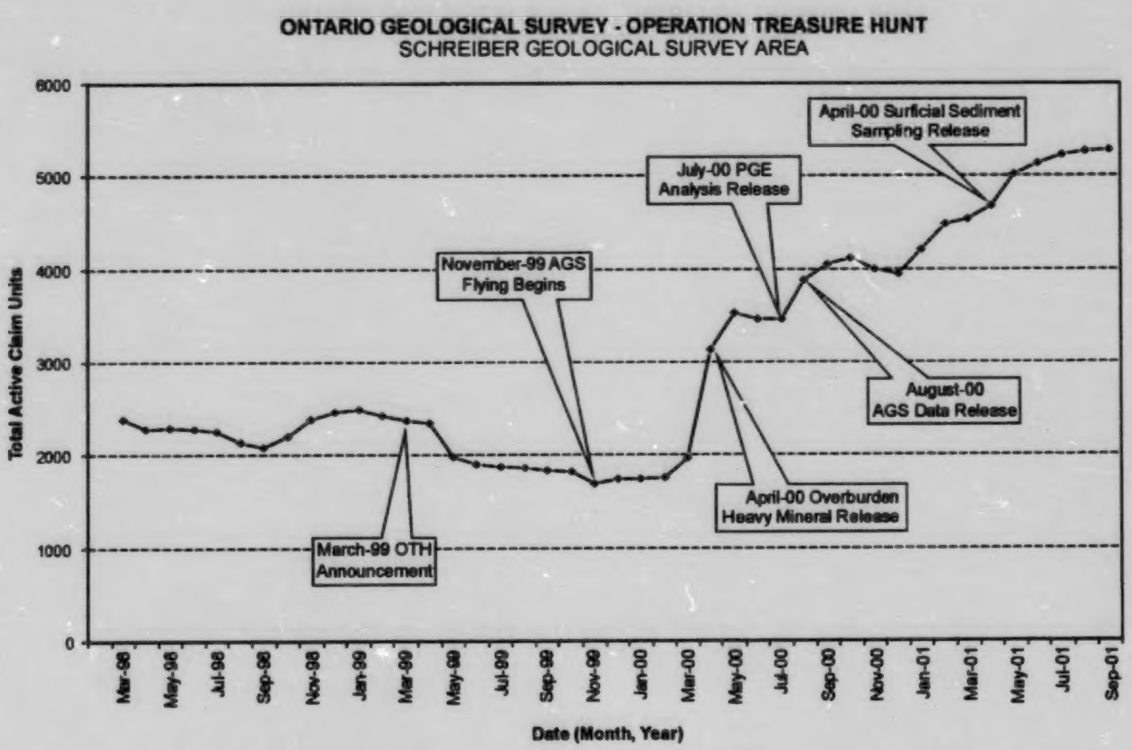

Figure 3.1. Change in total active mining claims, measured for the Schreiber geological survey area. The approximate dates of key announcements, activities or data releases are indicated. Total active claims are those claims in active standing on the date of this report. Abbreviations: AGS, airborne geophysical survey; PGE, platinum group element; OTH, Operation Treasure Hunt geoscience program.

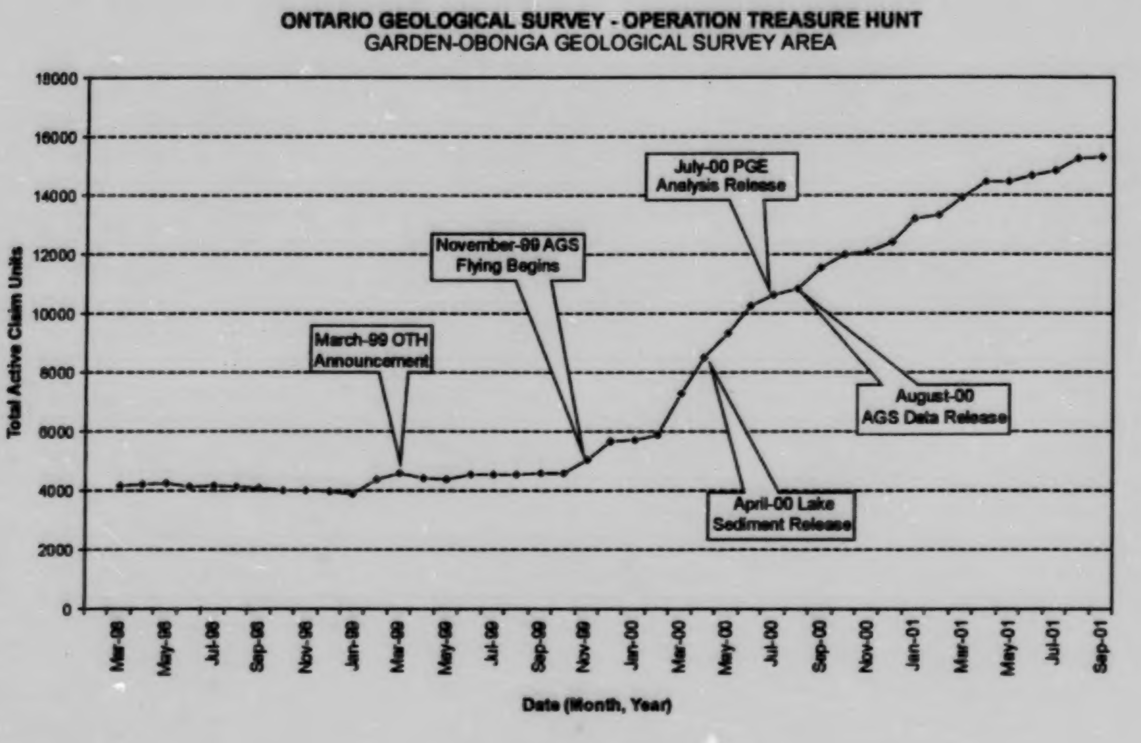

Figure 3.2. Change in total active mining claims, measured for the Garden–Obonga geological survey area. The approximate dates of key announcements, activities or data releases are indicated. Total active claims are those claims in active standing on the date of this report. Abbreviations: AGS, airborne geophysical survey; PGE, platinum group element; OTH, Operation Treasure Hunt geoscience program.

Short-Term Results: Client Testimonials

Client feedback and testimonials are short-term qualitative indicators of the impact of the OGS geoscience program (Table 3.2).

Table 3.2. Client testimonials are tracked as short-term indicators of client satisfaction and impact of the OGS geoscience program.

Client	Property	Testimonial
William McCrindle President, Berland Resources ltd.	Northwestern Ontario	"No previous exploration work is reported from any of the properties. All properties were staked based on the Ontario Government's Treasure Hunt airborne data release for the Garden Lake-Obonga Lake Area."
Grayme Anthony Houston Lake Mining Inc.	Northwestern Ontario	"Their [Dr. F Breaks, OGS and Dr. A. Tindle, Open University] extensive documentation of the pegmatite has depicted the second largest, complex-type, petalite subtype pegmatite in Ontario with highly anomalous to economically significant values of tantalum, cesium, rubidium, lithium, beryllium, niobium, tin, gallium, germanium and thallium."

Table 3.2. Continued

Client	Property	Testimonial
H. Douglas Hume Chairman and C.E.O., Nuinsco Resources Ltd.	Northwestern Ontario	"The OGS Study 56, provided the inspiration and data base which allowed Nuinsco to pick up where the OGS left off. We expect to succeed on this project with one or more mineable discoveries within our search area."
MacKenzie Watson President, Freewest Resources Canada Inc.	Northeastern Ontario	"No doubt that it was OGS products and services that put us there."
Richard Kantor President, Champion Bear Resources Ltd.	Northwestern Ontario	"The discovery, made by Dr. Fred Breaks of the Ontario Geological Survey, promoted a staking rush in the area and resulted in three separate drill programs from September to December, 1999."
Robin Dunbar President, Mustang Minerals Inc.	Northeastern Ontario	"The OGS work is invaluable to us. The background work the OGS sponsored was instrumental in attracting millions of investment dollars to the Sudbury area."
Donald S. Bubar President, Avalon Ventures Ltd.	Northwestern Ontario Properties	"The work of the Ontario Geological Survey was instrumental in the recognition of the rare metal pegmatite potential of the Separation Rapids and Raleigh Lake areas of northwestern Ontario."
Edward Ellwood President, Canmine Resources Corp.	Northwestern Ontario	"Jack Parker of the OGS was the first to recognize that the high-grade cobalt mineralization in the Werner Lake area is stratigraphically controlled. He accurately mapped this and provided systematic data to show that the cobalt deposits are skarns. Jack's mapping considerably aided exploration diamond drilling on the West Cobalt Deposit and helped to lead to a new discovery, the Eastern Shallows Cobalt Deposit. The West Cobalt Deposit is the focus of a feasibility study, which includes 846 feet of underground workings and could see a permanent production decision as early as 2001."

Medium- to Long-Term Results: Stages of Company Investment

Long-term sustainable economic mineral development for a geographic area or community depends partly on the successful development from mineral prospect to mine. The following 3 case studies illustrate the magnitude of private sector investment that range from early exploration (Figure 3.3: River Valley and East Bull Lake palladium-platinum project), advanced exploration (Figure 3.4: Separation Rapids petalite–rare metal project), to mine development (Figure 3.5: Agrium phosphate deposit).

In each of these case studies, the projects benefitted from the combined geoscience services provided by the Ontario Geological Survey; the mineral development services of the Mines Group and Mining Lands; and the economic development services of the Northern Development Division. Therefore, the private sector investment cannot be attributed 100% to a single government product or service. The private sector investment involved for each of these case studies illustrates the dramatic increase of economic impact on the immediate community and the provincial economy.

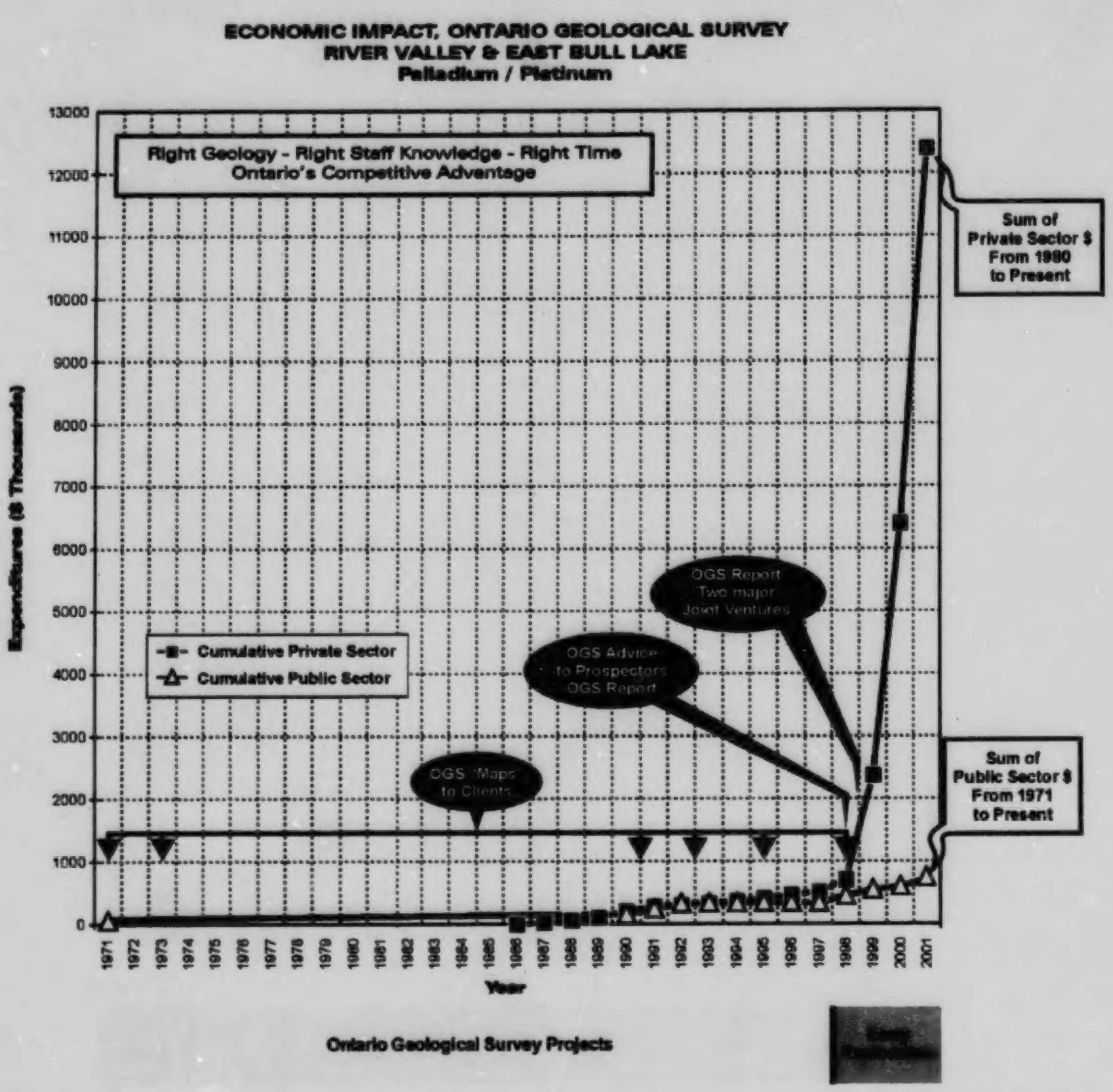

Figure 3.3. The East Bull Lake – River Valley platinum group element exploration play illustrates the medium-term economic impact triggered by Ontario Geological Survey activity. Following the initial public investment in Ontario Geological Survey activity, the cumulative private-sector investment in the East Bull Lake – River Valley platinum group element "play" has exceeded $12 million since 1998. The private sector acknowledges that the Ministry of Northern Development and Mines – Ontario Geological Survey services, products and geological survey work were instrumental in triggering the exploration and attracting private sector investment.

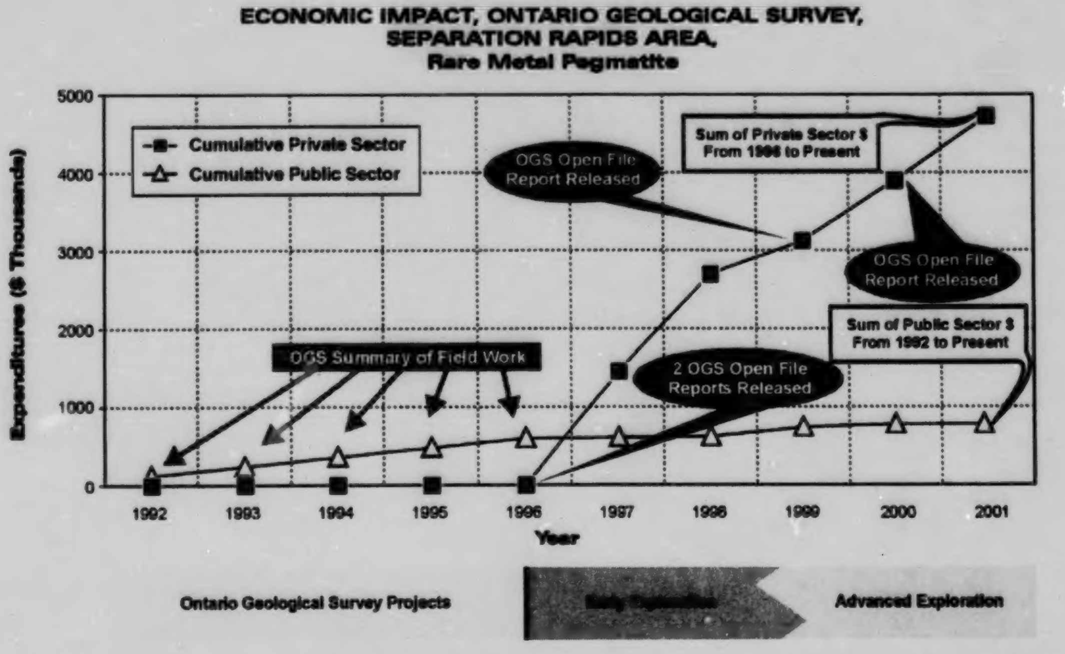

Figure 3.4. The Separation Rapids rare metal-petalite advanced exploration play illustrates the medium-term economic impact triggered by Ontario Geological Survey activity. Following the initial public investment in Ontario Geological Survey activity, the cumulative private-sector investment in the Separation Rapids area rare metal-petalite play has exceeded $4.8 million. The private sector acknowledges that Ontario Geological Survey services, products and geological surveys were instrumental in documenting the significance of the pegmatite field, triggering exploration and attracting private sector investment.

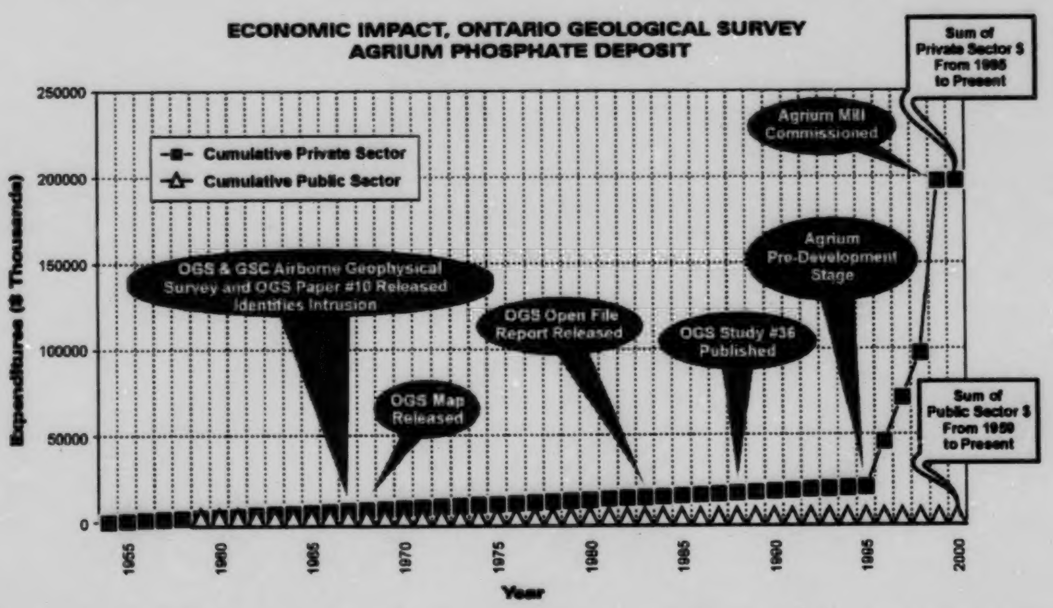

Figure 3.5. The Agrium Mine development history illustrates the long-term economic impact derived from an initial Ontario Geological Survey airborne geophysical survey that identified the location of a prospective rock; and, the 25-year involvement of Ministry of Northern Development and Mines staff in helping to promote the existence of, and development of, the mineral resource. To date, the private sector has invested in excess of $200 million in the project.

Long-Term Results: Science and Technology

The OGS geoscience program also has a longer term impact on the science and technology capacity of Ontario. Client testimonials document that the Operation Treasure Hunt geoscience program is having the following impact:

1. *Reid–Mahaffy Airborne Geophysical Test Range (Reford et al., this volume)*

The Reid–Mahaffy airborne geophysical test range, developed in collaboration with Falconbridge Limited, is used by many commercial airborne survey providers to test, calibrate, and benchmark their airborne geophysical systems. The Reid–Mahaffy test range represents a multi-depth conductor in a complex bedrock and Quaternary geological setting. The Reid–Mahaffy test site has created great interest in Canada and overseas, especially in Australia, where similar efforts are underway to duplicate this type of complex airborne electromagnetic test range.

2. *New Generation of Airborne Geophysical Survey Systems Introduced to Ontario*

The commitment of the Ontario Government to fund airborne geophysical surveys, through the Operation Treasure Hunt geoscience initiative, during a period of global market weakness, allowed the Ontario-based airborne geophysical industry to sustain their development and to provide Ontario-designed airborne electromagnetic survey technology. The short-term result was

- the introduction of Ontario-designed and built fixed-wing electromagnetic system to the Ontario, Canadian, and global markets
- the introduction of an Ontario-designed and built, new generation digital signal processing helicopter electromagnetic system
- the retention of specialized and knowledgeable high-technology Ontario jobs related to the airborne geophysical survey industry during a period of global contraction

Additionally, the government investment in the Operation Treasure Hunt geoscience initiative facilitated the first public demonstration of a new airborne geophysical system from South Africa to Ontario, the SPECTREM$_{2000}$.

3. *New Exploration-Relevant Geoscience Methods*

The surficial geochemical methods development applied research component of the OGS has focussed on developing new methods for the detection of mineralization in thick overburden covered areas. This work, completed in co-operation with CAMIRO, an industry funded research network, has developed new models and field methods.

The work stands on the threshold of

- revolutionizing surface geochemical exploration in Ontario
- dramatically lower exploration costs
- defining exploration targets than could not previously be "seen"
- discriminating between deeply buried barren and fertile targets on the basis of surficial geochemical response

This work represent a significant advance in the scientific and practical aspects of geochemical mineral exploration in areas of thick overburden.

James MacDonald, Chief Geologist, Billiton Minerals Canada Inc. stated

> *"[The OGS} presentation [on electrochemical theory and evidence] was stimulating and has significant implications for exploration. In my capacity as Chief Geologist at Billiton, I attempt to keep our geologists abreast of key development in their fields. I wish to obtain a copy of the presentation in order that I may circulate it to Billiton's exploration managers and project geologists."*

Long-Term Results: Geoscience Infrastructure in the Far North

Access to land in the far north (north of 51°) is, and has been, a concern to many mineral exploration clients due to the limited infrastructure and uncertainty of land tenure.

The limited physical infrastructure in far northern Ontario makes it extremely costly to carry out prospecting and grassroots exploration. The types of surveys required to gather the initial geological framework are costly. Through Operation Treasure Hunt, the OGS was able to provide regional geological survey information describing geographic areas that have not been mapped recently, for example, airborne geophysical surveys and geochemical surveys. This geoscience information will be the basis upon which private sector and First Nations explore or assess the mineral resources in the far north.

The OGS worked closely with the First Nation communities in close proximity to the far north survey areas; this allowed the building of relationships with these communities. In some instances, First Nation communities were awarded contracts to deliver services or conduct a sampling survey. In addition, the OGS participated in First Nation community meetings, band council meetings and community Open Houses to increase awareness about geoscience and geoscience inventories, for example, what airborne geophysical and indicator mineral surveys were and how the information from these surveys can be used.

The OGS hopefully provided additional opportunities for the members of these communities to consider and perhaps pursue careers in geoscience or related fields.

The OGS, in return, benefitted enormously from learning a new way of conducting business and becoming sensitized to the issues and concerns of far north communities. The OGS realized a deeper appreciation of the potential impacts of geoscience. It is hoped that mineral exploration clients will follow the industry best practices and build cultural and business relationships with First Nation communities.

NEXT STEPS: GEOSCIENCE-IMPACT QUESTIONNAIRE

By spring 2002, the OGS will introduce a client questionnaire to quantify the investment resulting from some of the Operation Treasure Hunt projects. The survey will be conducted by

- telephone interviews with claim and property holders
- questionnaire distributed through client association mail lists
- questionnaire distributed through registrant packages at mineral symposia

The client survey will acquire quantitative investment information to document the long-term economic, science and technology, and social impact of the Ontario Geological Survey geoscience program.

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4. Project Unit 95-24: The Abitibi Greenstone Belt: A Program Update

J.A. Ayer[1] **and N.F. Trowell**[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

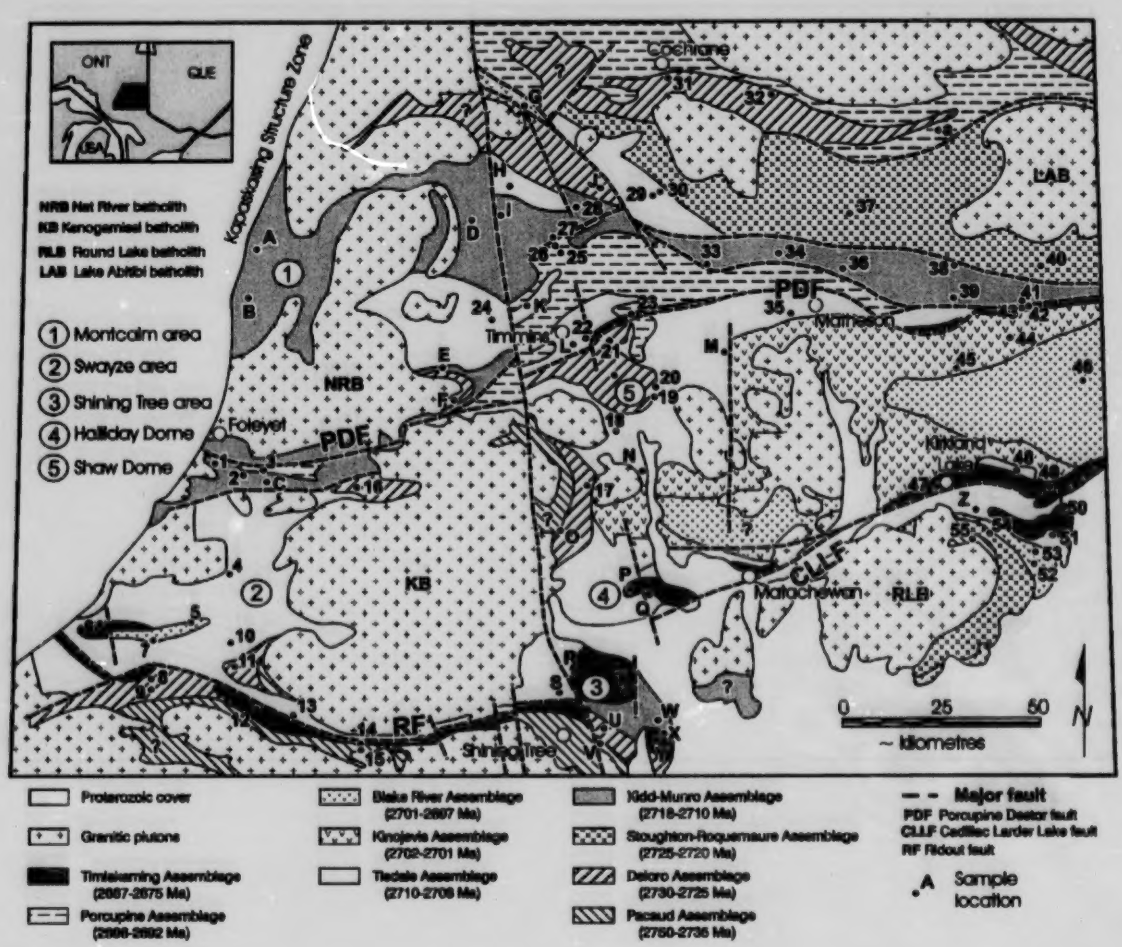
The Precambrian Geoscience Section (PGS) program in the Abitibi greenstone belt (AGB) is designed to facilitate exploration by providing current geological mapping covering areas of high economic potential at a variety of scales. We are also actively involved in research on the metallogeny and tectonic evolution of the belt and applied research on specific mineral deposit-related problems through jointly funded partnership projects with mining companies, the geology departments of several universities and other government agencies.

CURRENT PROJECTS

To date, the Abitibi compilation project has produced hard-copy and digital versions of the Timmins, Lake Abitibi and Kirkland Lake map areas at a scale of 1:100 000 (Ayer and Trowell 1998; Ayer, Trowell and Berger1999b; Ayer and Trowell 2000). New compilation sheets covering the Swayze and the Matachewan areas are planned for release in 2001 and 2002, respectively. The compilation, in conjunction with new geochronological and geochemical sampling, will enable further review of the assemblages (Figure 4.1), help to establish a more formalized stratigraphy, and help to construct new metallogenic and geodynamic models for the evolution of the Abitibi greenstone belt. A number of more detailed mapping and research projects at a variety of scales (discussed below) are designed to focus on areas where we currently have an inadequate understanding of the relationships between mineralization and geology, and to provide new data for the ongoing compilation project.

The past summers' mapping of Denton and Carscallen townships at 1:20 000 scale (Hall, this volume) is part of multiple year project (Vaillancourt 2000) to improve our knowledge of the distribution of rock units and structures in a poorly understood part of the AGB, that is located southwest of Timmins. The area, in proximity to the westward extension of the Porcupine–Destor deformation zone, has good potenial to host gold deposits and is also being actively explored for copper-zinc base metal deposits.

New mapping of Burrows, Kemp and Mond townships at 1:20 000 scale (Machado, this volume) extends recent mapping in the Shining Tree area (Johns and Amelin 1999) to the north. These 3 townships were previously mapped by the OGS only at reconnaissance scale. They are, in part, covered by Proterozoic sediments, but significant portions are underlain by AGB bedrock (some areas of which have not been indicated on any previous OGS maps). The area is considered to have good potential for base metal mineralization, gold mineralization (in proximity to the extension of the Cadillac–Larder Lake fault, west of Matachewan) and nickel-copper (-platinum group elements) (-PGE) mineralization on strike with the Sothman prospect located immediately to the north in Sothman Township.


ONT
QUE
USA
NRB Nat River batholith
KB Kenogamisi batholith
RLB Round Lake batholith
LAB Lake Abitibi batholith
① Montcalm area
② Swayze area
③ Shining Tree area
④ Halliday Dome
⑤ Shaw Dome
Kapuskasing Structure Zone
Cochrane
Timmins
Matheson
Foleyet
Kirkland Lake
Matachewan
Shining Tree
NRB
KB
RLB
LAB
PDF
PDF
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0 25 50
~ kilometres
N
Proterozoic cover
Granitic plutons
Timiskaming Assemblage (2687-2675 Ma)
Porcupine Assemblage (2696-2692 Ma)
Blake River Assemblage (2701-2697 Ma)
Kinojevis Assemblage (2702-2701 Ma)
Tisdale Assemblage (2710-2703 Ma)
Kidd-Munro Assemblage (2718-2710 Ma)
Stoughton-Roquemaure Assemblage (2725-2720 Ma)
Deloro Assemblage (2730-2725 Ma)
Pacaud Assemblage (2750-2735 Ma)
Major fault
PDF Porcupine Destor fault
CLLF Cadillac Larder Lake fault
RF Ridout fault
A Sample location

Figure 4.1. Distribution of southern Abitbi greenstone belt assemblages in Ontario (*see* Table 4.1 for details). Letters indicate the locations of samples used for U/Pb geochronology as part of the compilation project and numbered locations are for previously reported U/Pb geochronology samples (*see* Tables 4.2 and 4.3 for data and sources).

A PhD thesis project, by H.S. Oliver at University of Portsmouth, UK, is currently documenting the geochemical patterns of the various Archean rock packages in the Shining Tree area (Oliver et al. 2000). This data will be used in conjunction with the mapping by G.W. Johns to help evaluate the evolution and geodynamic framework of this part of the Abitibi greenstone belt. An ongoing MSc research project (Leblanc et al., this volume) will help understand the geology and help characterize base metal and gold mineralization in Macmurchy Township.

A new 1:20 000 scale mapping project was initated this summer to map a number of townships along the Larder–Cadillac deformation zone east of Matachewan (Berger, this volume). Past township-scale mapping and associated research, along the Porcupine–Destor fault from Timmins to the Quebec border, has revealed a number of lithological, structural and stratigraphic factors which appear to be critical in focussing gold mineralization (Berger, this volume; Benn et al., this volume). In recent years, a number of thesis projects were initiated, which focus on problems related to the controls of gold mineralization along the Porcupine–Destor fault. These include a recently completed MSc thesis by

J. Ropchan and an ongoing PhD thesis by B. Luinstra. These projects were supported by the Ontario Geological Survey, the University of Ottawa and 2 mining companies, with the objectives of evaluating the geochemistry of the host rocks and alteration associated with gold mineralization, and the timing and structural controls of mineralization at the Holloway and Holt–McDermott mines (Ropchan et al., submitted). L. Pigeon, in preparing a MSc thesis, is currently researching the petrogenesis of the syenitic plutons in proximity to the Porcupine–Destor deformation zone east of Matheson and their genetic relationships to gold mineralization (Pigeon et al., this volume).

Collaborative projects with the Mineral Exploration Research Centre (MERC) at Laurentian University have the goals of examining the spatial and stratigraphic variations in AGB komatiites in order to provide constraints on their petrogenesis and the stratigraphic architecture and assembly of the Abitibi greenstone belt (Sproule et al., 2000). An ongoing PhD thesis project has the aim of studying the volcanic facies of komatiite in the AGB in order to constrain stratigraphic, tectonic and metallogenic models (Houlé et al., this volume). These projects will help us to understand if komatiites within individual assemblages possess distinctive geochemical and/or facies types and whether komatiite-associated nickel-copper (-PGE) deposits occur at specific stratigraphic levels and in association with specific lava facies or magma types. The ultimate goal of this research is to aid in the exploration for new magmatic nickel-copper (-PGE) sulphide deposits.

A postdoctoral research project, supported by the Ontario Geological Survey, the University of Ottawa and the German Research Foundation (DFG), is studying the role of the large granitoid intrusions in the Abitibi greenstone belt. The study concentrates on fabric development in a batholith to correlate deformational processes in batholiths with those in the greenstone belts. This work will ultimately help understand the role of batholiths in providing structures and fluids for greenstone belt mineralization. The chosen working area, the Kenogamissi batholith (Becker et al., this volume), is structurally comparable to other granitoid intrusions in Archean greenstones and, therefore, can provide information on crustal and mineral deposit development during the last stages of the formation of continental crust. Since these intrusions usually only contain minor, if any, mineral deposits, they are not well characterized, therefore, little is known about the mechanisms of granitoid intrusions in Archean cratons. More rarely studied is the connection of the emplacement history of batholiths with the evolution of the bordering greenstone belts and subsequent mineralization. This information can be used to develop a model for the evolution and crustal formation of the craton, including possible mineral deposits in the host rocks of the batholith.

NEW DEVELOPMENTS IN THE ABITIBI GREENSTONE BELT

Geological models for the Abitibi greenstone belt are changing rapidly. The Precambrian Geoscience Section has profoundly modified the understanding of Precambrian greenstone belts by the advancement of the assemblage concept (Thurston and Chivers 1990). Jackson and Fyon (1991) applied the concept to the Abitibi Subprovince in Ontario and identified 71 assemblages. Jackson, Fyon and Corfu (1994) interpreted the Abitibi greenstone belt assemblages as Archean analogues to a variety of modern geodynamic settings representing largely allochthonous terranes juxtaposed into their current positions by plate tectonic processes along active continental margins. However, recent mapping and geochronological determinations have led to reinstatement of the more traditional autochthonous stratigraphic model for the southern Abitibi greenstone belt, revealing that ,when unfolded, a largely coherent stratigraphic succession with similar ages and rock types exists in the Abitibi greenstone belt (Heather 1998; Ayer et al. 1999a). The autochthonous model is also strongly supported by widespread evidence of inherited zircons representing the ages of underlying stratigraphy within the overlying volcanic units, thus indicating that upper stratigraphic volcanic units erupted through older units.

Tectonostratigraphic revision utilizing new geochronologic data and the results of regional-scale compilation have resulted in subdivision of the AGB into 9 distinct stratigraphic assemblages identified on the basis of geochronological, lithological and temporal criteria (Ayer et al. 1999a). We have now extended this subdivision into the Swayze greenstone belt and have made revisions to earlier schemes, based on the integration of all available U/Pb geochronological data for supracrustal rocks with the geological compilation results (*see* Figure 4.1; Tables 4.1, 4.2 and 4.3). These data will be presented with more thorough analysis and synthesis in an upcoming special issue on the Abitibi Subprovince planned for publication in *Precambrian Research* in 2002 (Ayer et al., in press).

Table 4.1. Summary of southern Abitibi greenstone belt supracrustal assemblage names, ages, basal contacts, rock types and chemical affinities.

Assemblage Name (Age in Ma)	Includes all or parts of assemblages from Jackson and Fyon (1991)	Basal Contact Relationships	Dominant Rock Types	Volcanic Chemical Affinity
Timiskaming (2687 to 2675)	Garrison, Hearst, Midlothian, Natal, Ridout, Timiskaming, Three Nations	Unconformable	Conglomerate, sandstone, mafic to intermediate volcanic	Alkalic to calc-alkalic
Porcupine (2696 to 2690)	Hoyle, Porcupine, Scapa, Whitney	Unconformable	Turbidite, minor conglomerate and iron formation	None observed
Blake River (2701 to 2697)	Blake River, Halcrow–Swayze, Krist, Skead, Watabeag	Conformable to disconformable	Mafic to felsic volcanic	Tholeiitic and calc-alkalic
Kinojevis (2702 to 2701)	Geike, Kinojevis (North and South), Watabeag	Conformable	Mafic and minor felsic volcanic	Tholeiitic
Tisdale (2710 to 2703)	Boston, Bowman, Cabot–Kevin, Duff–Rand, Eldorado, Kamiskotia, Garnet–Tooms, Geike, Halcrow–Swayze, Halliday, Horwood, Larder Lake, McElroy, Shining Tree, Tisdale, Watabeag	Conformable to disconformable	Ultramafic, mafic, intermediate to felsic volcanic and iron formation	Komatiitic, tholeiitic and calc-alkalic
Kidd–Munro (2719 to 2711)	Cabot–Kevin, Carscallen, Duff–Rand, Hong Kong, Kamiskotia, Kidd–Munro, Shining Tree	Conformable to disconformable	Ultramafic, mafic, intermediate and felsic volcanic and iron formation	Komatiitic, tholeiitic and calc-alkalic
Stoughton–Roquemaure (2723 to 2720)	Catherine–Pacaud, Kinojevis North, Stoughton–Roquemaure	Conformable to disconformable	Ultramafic, mafic, intermediate and felsic volcanic	Komatiitc, tholeiitic and calc-alkalic
Deloro (2730 to 2724)	Adair, Bartlett, Cabot–Kevin, Carscallen, Deloro, Eldorado, Hanrahan, Hong Kong, Marion, Stoughton–Roquemaure, Shining Tree	Disconformable	Mafic, intermediate and felsic volcanic and iron formation	Tholeiitic and calc-alkalic
Pacaud (2750 to 2735)	Catherine–Pacaud, Hong Kong, Peterlong, Marion, Shining Tree, Sinclair	Unknown—removed by batholith intrusions	Ultramafic, mafic and felsic volcanic	Komatiitic, tholeiitic and calc-alkalic

Table 4.2. Summary of new U/Pb geochronological results from the PGS compilation project in the Abitibi greenstone belt (*see* Figure 4.1 for locations).

Sample	Assemblage	Rock Type	Depositional Age	Inherited Age(s)
A	Kidd–Munro	Felsic lapilli tuff	2710.0 ± 1.9	
B	Kidd–Munro	Felsic volcanic	2717.6 ± 2.3	2720
C	Kidd–Munro	Felsic lapilli tuff	2711.4 ± 2.6	
D	Kidd–Munro	Felsic volcanic	2719.5 ± 1.7	
E	Kidd–Munro	Felsic tuff	2712.8 ± 1.2	
F	Deloro	Felsic flow	2724.8 ± 1.0	2736
G	Blake River	Felsic volcanic	2694.1 ± 4.5	
H	Tisdale	Felsic flow	2703.0 ± 1.9	
I	Kidd–Munro	Felsic tuff breccia	2719.1 ± 5.1	
J	Deloro	Felsic lapilli tuff	2723.1 ± 1.2	
K	Tisdale	Felsic flow	2702.3 ± 1.4	
L	Tisdale	Mafic flow	2706.9 ± 3.1	
M	Tisdale	Felsic tuff	2703.7 ± 1.5	
N	Tisdale	Intermediate lapilli tuff	2702.0 ± 3.0	2723
O	Deloro	Felsic flow	2727.9 ± 2.2	
P	Timiskaming	Sandstone	<2689.6 ± 3.1	2715; 2706
Q	Tisdale	Felsic flow	2710.5 ± 1.6	
R	Timiskaming	Sandstone	<2687.0 ± 3.0	2715
S	Tisdale	Felsic tuff	2708.0 ± 1.0	
T	Timiskaming	Felsic tuff breccia	2687.0 ± 1.0	
U	Deloro	Felsic flow	2726.0 ± 1.3	2744; 2741
V	Pacaud	Felsic lapilli tuff	2741.3 ± 9.8	
W	Kidd–Munro	Felsic tuff breccia	2716.7 ± 1.7	
X	Timiskaming	Felsic flow	2687.9 ± 1.2	
Y	Timiskaming	Sandstone	<2701.6 ± 1.4	2740
Z	Tisdale	Felsic tuff breccia	2710.1 ± 3.9	2723
a	Porcupine	Wacke	<2698.8 ± 2.4	2825; 2745; 2725; 2715

Table 4.3. Compilation of U/Pb ages from other sources (*see* Figure 4.1 for locations).

Sample	Age (Ma)	Inheritance	Assemblage	Rock Type	Reference
1	<2717		Kidd–Munro	Felsic flow breccia	Heather and Shore (1999)
2	2718 ± 2		Kidd–Munro	Felsic volcanic	Heather and Shore (1999)
3	<2696		Porcupine	Sandstone	Heather and Shore (1999)
4	2702 ± 2		Tisdale	Felsic volcaniclastic	Heather and Shore (1999)
5	2697 ± 1		Blake River	Felsic volcaniclastic	Cattell et al. (1984)
6	<2690		Timiskaming	Sandstone	Heather and Shore (1999)
7	2695 ± 2		Blake River	Felsic tuff	Heather and Shore (1999)
8	2724 ± 2		Deloro	Felsic volcaniclastic	Heather and Shore (1999)
9	2731 ± 2		Deloro	Felsic lapilli tuff	Heather and Shore (1999)
10	2705 ± 2	2730 to 2740	Tisdale	Felsic volcanic	Heather and Shore (1999)
11	2729 ± 5	2740 to 2750	Deloro	Felsic tuff	Heather and Shore (1999)
12	<2690	2735 to 2745	Timiskaming	Sandstone	Heather and Shore (1999)
13	2707 ± 2		Tisdale	Intermediate tuff	Heather and Shore (1999)
14	2734 ± 2		Pacaud	Felsic lapilli tuff	Heather and Shore (1999)
15	2739 ± 2		Pacaud	Felsic lapilli tuff	Heather and Shore (1999)
16	2730 ± 2		Deloro	Felsic lapilli tuff	Heather and Shore (1999)
17	2727 ± 1		Deloro	Dacite tuff	Corfu and Noble (1992)
18	2703 ± 2	2725 ± 2	Tisdale	Felsic lapilli tuff	Corfu et al. (1989)
19	2724 ± 2		Deloro	Felsic volcanic	Barrie and Corfu (1999)
20	2708 ± 2	2724	Tisdale	Felsic volcanic	Barrie and Corfu (1999)
21	2725 ± 1		Deloro	Felsic volcanic	Corfu and Noble (1992)
22	2698 ± 4		Blake River	Felsic lapilli tuff	Corfu et al. (1989)
23	<2679 ± 3	2685 to 2693	Timiskaming	Sandstone	Corfu et al. (1991)
24	2705 ± 2		Tisdale	Felsic volcanic	Barrie and Davis (1990)
25	<2685 ± 6	2696 to 2700	Porcupine	Volcaniclastic	Bleeker and Parrish (1996)
26	<2699	2710 to 2715	Porcupine	Greywacke	Bleeker and Parrish (1996)
27	2710 –17	2723 to 2735	Kidd–Munro	Felsic volcanic	Bleeker et al. (1999)
28	2716 +6/–3		Kidd–Munro	Felsic volcanic	Barrie and Davis (1990)
29	2706 ± 2		Tisdale	Felsic tuff	Ayer et al. (1997)
30	2705 ± 2		Tisdale	Felsic volcanic	Barrie et al. (submitted)
31	2725 +7/–5		Deloro	Felsic tuff	Barrie and Corfu (1999)
32	2726 +7/–5		Deloro	Felsic volcanic	Barrie and Corfu (1999)
33	2717 ± 1		Kidd–Munro	Felsic flow	Barrie and Corfu (1999)
34	2710 ± 2		Kidd–Munro	Felsic flow	Barrie et al. (submitted)
35	2706 ± 2		Tisdale	Intermediate tuff	Corfu and Noble (1992)
36	2714 ± 2		Kidd–Munro	Felsic flow	Corfu et al. (1989)
37	2722 ± 1		Stought–Roque.	Felsic tuff	Barrie et al. (submitted)
38	2716 ± 3	2723 ± 2	Kidd–Munro	Felsic flow	Barrie et al. (submitted)
39	2713 ± 2		Kidd–Munro	Felsic volcanic	Corfu et al. (1989)
40	2723 ± 2	2731	Stought–Roque.	Felsic lapilli tuff	Barrie (1999)
41	2716 ± 2		Kidd–Munro	Intermediate tuff breccia	Berger and Amelin (1999)
42	<2687 ± 2	2695 to 2717	Timiskaming	Volcaniclastic	Ropchan et al. (submitted)
43	<2684 ± 1	2695 to 2724	Timiskaming	Sandstone	Ropchan et al. (submitted)
44	2701 ± 1		Kinojevis	Felsic flow	Berger and Amelin (1999)
45	2701 ± 3		Kinojevis	Felsic volcanic	Corfu and Noble (1992)
46	2701 ± 2		Blake River	Felsic volcanic	Corfu et al. (1989)
47	<2680 ± 3	2690 to 2723	Timiskaming	Sandstone	Corfu et al. (1991)
48	2700 ± 3		Tisdale	Felsic volcanic	Corfu (1993)
49	2677 ± 2		Timiskaming	Volcaniclastic	Corfu et al. (1991)
50	2679 ± 3		Timiskaming	Sandstone	Corfu et al. (1991)
51	2705 ± 2		Tisdale	Felsic fragmental	Corfu et al. (1989)
52	2701 +3/–2	2720	Blake River	Felsic fragmental	Corfu (1993)
53	2701 +3/–2		Blake River	Felsic fragmental	Corfu et al. (1989)
54	2720 ± 2		Stought–Roque.	Mafic flow	Corfu and Noble (1992)
55	2747 ± 2		Pacaud	Felsic volcanic	Mortensen (1993)

CONCLUSIONS

In summary, many exciting new advances in our understanding of the geology of the Abitibi greenstone belt are being made. The following reports in this volume demonstrate the merits of a diverse, but balanced, approach to Abitibi area geology using the traditional strengths of Precambrian Geoscience Section mapping, the comphrensive understanding of the ore deposits by the mining companies and the research skills of university geology departments. This balanced approach embraces projects at the wide variety of scales and methodologies that are required for the range of problems that exist. The projects range from belt-wide compilation, to regional synoptic mapping, from township-scale and to extremely detailed mine-scale mapping. The program is also focussed on the economically important parts of the belt in Ontario. We feel our integrated approach to applied research through collaboration with many of our mining company clients and the earth science departments of a number of universities is needed to advance our understanding of the geology and its relationship to mineral deposits in this geologically complex, but highly productive, part of the province. We also feel confident that the maps, reports and theses resulting from this comprehensive program will provide many new ideas and concepts that are, and that will continue to be, directly applicable to exploration for new mineral deposits.

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5. Project Unit 00-011. Geology and Mineral Potential of Carscallen and Denton Townships, Timmins West Area

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INTRODUCTION

As one of the world's most economically significant greenstone belts, the Abitibi greenstone belt has been the focus of mineral exploration for nearly a century. Mineral exploration becomes more challenging as prospectors and geologists are forced to move into areas that are poorly understood geologically due to extensive overburden and structural complexities. In an effort to facilitate these activities, the Precambrian Geoscience Section of the Ontario Geological Survey has been conducting township-scale (1:20 000) bedrock mapping in some of the least understood parts of the Timmins region. The current project has focussed on Carscallen and Denton townships as a follow-up to the bedrock mapping in Bristol and Ogden townships in 2000 (Vaillancourt 2000; Vaillancourt, Pickett and Dinel 2001).

The goals of this project are three-fold: 1) to clarify some lithological uncertainties and to refine the map boundaries; 2) to evaluate mineral potential of an Ontario Living Legacy site recently established in Denton Township; and 3) to ascertain the whereabouts and nature of the regionally significant Porcupine–Destor deformation zone. Geophysical and diamond-drill hole data are being used to aid in the extrapolation of geological contacts across the many large areas obscured by overburden.

The centre of the map area is approximately 30 km southwest of the City of Timmins and covers a 200 km^2 area. Ready access is afforded by Highway 101, which bisects the area, as well as numerous forestry roads, most notably the Malette Road, the "Old Malette Road" and the road leading to and past the Star Lake garbage dump. The Tatachikapika River cuts diagonally across southeastern Denton Township, offering boat access when there is enough water.

A geological compilation of the Timmins area at a scale of 1:100 000 (Ayer and Trowell 1998) encompasses the map area. Denton Township was part of a 3 township bedrock mapping project conducted by Choudhry (1982, 1989) at a scale of 1:15 840. Carscallen Township was included in a geological mapping project of the Kamiskotia area (1:50 000 scale: Barrie 1990, 1992, 2000).

REGIONAL SETTING

The Abitibi Subprovince of the Superior Province comprises a stratigraphically continuous succession of Archean metavolcanic and metasedimentary rocks that developed in an ensimatic basin (Ayer et al., in press). The Deloro, Kidd–Munro and Tisdale volcanic and the Porcupine sedimentary assemblages (Ayer et al. 1999) and the Kamiskotia Gabbroic Complex (Barrie 1990, 1992, 2000) are exposed in the map area (Figure 5.1) and the general Timmins West region. Archean felsic plutons and associated dikes intrude all of the aforementioned units. Proterozoic mafic dikes cut the Archean rocks.

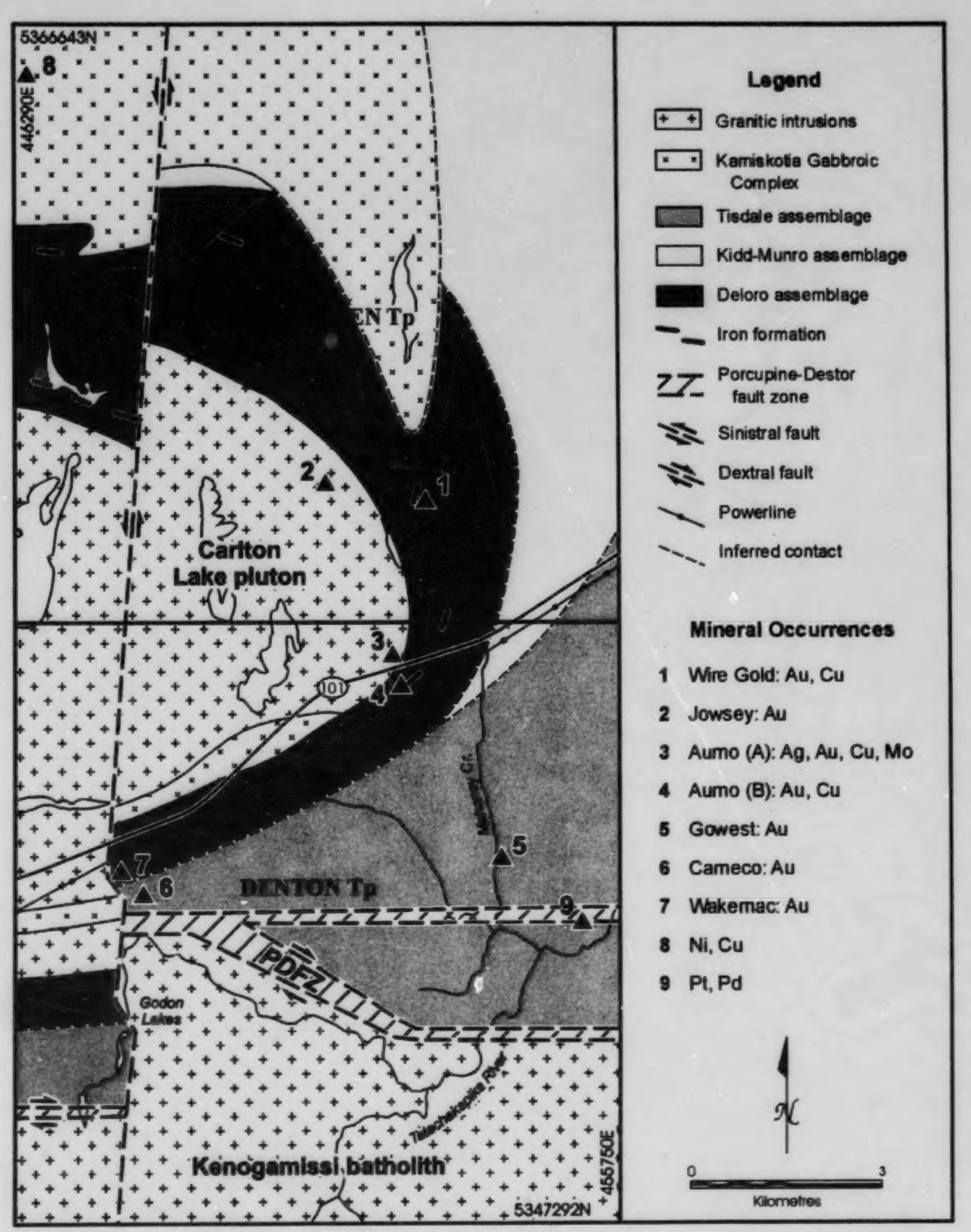
5366643N
446290E
8
ENTp
2
1
Carlton Lake pluton
3
4
101
Mahoney Cr.
5
7
6
DENTON Tp
9
PDFZ
Godon Lakes
Tatachikapika River
Kenogamissi batholith
455750E
5347292N
Legend
Granitic intrusions
Kamiskotia Gabbroic Complex
Tisdale assemblage
Kidd-Munro assemblage
Deloro assemblage
Iron formation
Porcupine-Destor fault zone
Sinistral fault
Dextral fault
Powerline
Inferred contact
Mineral Occurrences
1 Wire Gold: Au, Cu
2 Jowsey: Au
3 Aumo (A): Ag, Au, Cu, Mo
4 Aumo (B): Au, Cu
5 Gowest: Au
6 Cameco: Au
7 Wakemac: Au
8 Ni, Cu
9 Pt, Pd
N
0
3
Kilometres

Figure 5.1. General geology of Carscallen and Denton townships. Abbreviation: PDFZ, Porcupine–Destor fault (or deformation) zone.

Mafic to felsic, calc-alkalic metavolcanic rocks and associated iron formation characterize the Deloro assemblage (Ayer et al. 1999, in press). Zircons obtained from the felsic metavolcanic rocks yield U/Pb ages of 2724 to 2730 Ma (Corfu 1993; Ayer et al. 1997; Barrie and Corfu 1999). As such, these are the oldest known rocks in this area.

The Kidd–Munro assemblage that hosts the Kidd Creek volcanogenic massive sulphide (VMS) deposit, Canada's largest VMS deposit, comprises a suite of tholeiitic and komatiitic rocks with local interlayers of high silica FIIIb-type rhyolites (Lesher et al. 1986) and a suite of calc-alkalic felsic to intermediate metavolcanic rocks. U/Pb zircon ages range from 2719 to 2710 Ma (Corfu 1993; Bleeker and Parrish 1996; Ayer et al. 1999, in press; Barrie and Corfu 1999) in this assemblage.

The rocks of the Tisdale assemblage are subdivided into 3 lithological suites with zircons yielding ages of 2710 to 2703 Ma (Corfu 1993; Ayer et al. 1999, in press; Barrie and Corfu 1999): 1) tholeiitic mafic to komatiitic metavolcanic rocks, locally associated with high silica rhyolite; 2) felsic to intermediate, calc-alkalic pyroclastic metavolcanic rocks; and 3) iron formation (Ayer et al. 1999). The Kamiskotia Gabbroic Complex is temporally associated with the Tisdale assemblage and intrudes the Deloro and Kidd–Munro assemblages.

Detrital zircons from the Porcupine assemblage metasedimentary rocks yield a stratigraphically defined range of maximum ages of 2696 Ma through 2692 Ma (Ayer et al. 1999, in press). Characterized by turbidites and minor conglomerates, these rocks represent the end of volcanism. Their deformed state, however, demonstrates that tectonism continued after their deposition.

GEOLOGY OF DENTON AND CARSCALLEN TOWNSHIPS

The townships of Denton and Carscallen are underlain by metavolcanic rocks of the Deloro, Kidd–Munro and Tisdale assemblages; metasedimentary rocks of the Porcupine assemblage and mafic and felsic intrusive bodies. Due to structural complexities, including the regionally significant Porcupine–Destor deformation zone, the various assemblages are interleaved and offset. Locally extreme alteration has obscured the nature of the metavolcanic and metasedimentary rocks leaving the assemblages more difficult to distinguish. An attempt has been made to distinguish the assemblages based solely on field observations and stratigraphic relationships (*see* Figure 5.1), however, this will likely be subject to modification when lithogeochemical and petrographic results have been assessed.

The Deloro Assemblage

Intimately interlayered (10 to 100 m) mafic and felsic metavolcanic rocks typify the bimodal Deloro assemblage in the map area. The dominant rock type is mafic metavolcanic flow that locally displays pillows, disrupted pillows and porphyritic texture with feldspar and altered mafic phenocrysts. Felsic metavolcanic horizons also display a variety of textures including lapilli-size lithic fragments in both porphyritic and aphyric matrices and matrix-supported crystal tuffs (typically feldspar-phyric, but quartz-feldspar-phyric and quartz-phyric examples are also exposed). One exposure, in western Denton Township just north of Highway 101, includes an horizon of feldspar-phyric felsic to intermediate flows wherein the euhedral to subhedral phenocrysts exceed 3 cm in diameter. Mafic sills within the felsic to intermediate metavolcanic horizons are common.

Chert-rich banded iron formation and closely associated clastic and/or chemical metasedimentary rocks occur within the metavolcanic pile near its stratigraphic top. Two chert horizons were identified:

1. A chert horizon associated with felsic metavolcanic rocks and limited to the northern extent of the Deloro assemblage in Carscallen Township is traceable into Whitesides Township to the west.
2. A chert horizon, associated with mafic metavolcanic rocks, that can be traced by mapping and geophysical interpretation around the Carlton Lake pluton into Denton and Keefer townships from north of the pluton in Carscallen and Whitesides townships.

The Deloro assemblage rocks in the map area display extensive deformation, manifested by a penetrative foliation that is locally folded, crenulated, kinked, brittley offset and either intensified by or crosscut by shear zones. Often, several of these features are apparent in the same exposure. Greenschist-facies metamorphism is manifested as chlorite and/or sericite minerals defining the main foliation everywhere in this unit. Garnet porphyroblasts were observed in a few locations. Alteration is variable and includes iron carbonate alteration, chlorite alteration, silicification and chlorite spots.

Kidd–Munro Assemblage

A thick pile of felsic metavolcanic rocks in the northeastern region of the map area is interpreted to be Kidd–Munro assemblage. An age (2713 Ma), similar to that of the Kidd–Munro assemblage, was determined (Ayer et al. 1999) from a rhyolite outcrop in northwestern Carscallen Township. This dated rock unit is separated from the bulk of the interpreted unit by a tongue of the younger Kamiskotia Gabbroic Complex (*see* Figure 5.1). The correlation across the intrusive body is based on textural and compositional considerations as well as the degree of deformation. Good metavolcanic and volcano-sedimentary textures including tuffaceous beds with truncated slump folds, cuspate glass shards (interpreted by the author as fiamme), rare bombs and flow banding are preserved. Horizons containing abundant quartz phenocrysts (up to 15%) are a distinctive feature of the felsic metavolcanic rocks in the Kidd–Munro assemblage.

The interpreted Kidd–Munro felsic metavolcanic rocks show a variety of colours on the fresh surface including light green, light grey, dark green, dark grey and black. This colour variation seems to reflect the degree of sericitization. These rocks do not display the uniform degree of metamorphism and deformation displayed by the Deloro assemblage rocks. A moderately penetrative foliation is present in zones of high strain including fold closures (F_2?) and small shear zones. In these areas, the rocks are more sericitized and display a lighter appearance on the fresh surface.

Bluish, high-iron and titanium ("Fe-Ti") basaltic flows (Vaillancourt 2000) are interlayered with the felsic metavolcanic rocks over a 150 m section in the northeastern corner of Carscallen Township. These basalts preserve large amoeba-shaped pillows.

Tisdale Assemblage

Limited exposure and proximity to the Porcupine–Destor deformation zone have obscured the primary characteristics of the Tisdale assemblage in the map area. However, the typical intimate interleaving of mafic and komatiitic metavolcanic rocks of the lower-most suite of the Tisdale assemblage is present in the rocks exposed in an east- trending band across central Denton Township. Relatively high magnetic, ultramafic rocks that display rare spinifex have been interpreted as komatiitic (pending lithogeochemistry results). These rocks are variably deformed and altered and include black aphanitic to fine-grained rocks with only a weak foliation; soft green serpentinites; and white and dark blue talcose schists. These units rarely extend more than 100 m across strike and are everywhere exposed in proximity to mafic metavolcanic rocks that also display a range of alteration and strain states. Penetratively foliated felsic metavolcanic (quartz-sericite schist) rocks are exposed in an horizon in the northern extent of this assemblage in the map area. Other felsic metavolcanic horizons, reported in diamond-drill core, are associated with mafic and ultramafic metavolcanic rocks in this vicinity.

In the area of the Godon Lakes (*see* Figure 5.1), massive, poorly sorted metawackes contain angular feldspar grains; rare, small, fuchsite clasts; horizons rich in quartz crystals; and limited sedimentary structures. These metasedimentary rocks are intimately associated with thin mafic and ultramafic metavolcanic horizons and are herein included in the Tisdale assemblage.

Kamiskotia Gabbroic Complex

The Kamiskotia Gabbroic Complex underlies the northwest corner of Carscallen Township. This compositionally texturally heterogeneous intrusive body has been interpreted as genetically related to the metavolcanic rocks of the Tisdale assemblage through textural, mutually crosscutting relationships, geochemical characteristics, and U/Pb age criteria (Barrie 1990, 1992, 2000). The complex is composed of both mafic and ultramafic intrusive rocks, however, only mafic intrusive rocks were observed in the map area by the author. Gabbro, gabbro-norite and limited olivine gabbro display a range of textures from equant, fine grained and massive through pegmatitic phases. Cumulate layering observed elsewhere in the complex (Barrie 1990, 1992, 2000) was not observed in Carscallen Township during the present study. Primary textural and compositional changes were observed across a distance of 10 m or less on most exposures within the complex.

Exposures of gabbroic rocks south of and within the Carlton Lake pluton are herein associated with the Kamiskotia Gabbroic Complex. These rocks display textural and compositional variations similar to those found in the main body of the complex. The gabbroic rocks locally cut the Carlton Lake pluton, but the gabbros are also cut by dikes associated with the pluton. This implies an intimate temporal relationship between these 2 intrusive units.

Porcupine Assemblage

Typical turbiditic metasedimentary rocks of the Porcupine assemblage were only observed in 1 area close to Mahoney Creek, approximately 2 km north of the Tatachikapika River in Denton Township. In these exposures, fine- to medium-grained wackes grade into shales in repeated Bouma sets less than 1 m wide. Grading, scours and flames were interpreted as indicating tops to the south. All other interpreted metasedimentary rocks observed in the field area are considered herein to be epiclastic and chemical metasedimentary deposits within the metavolcanic strata. Exposure of the Porcupine assemblage metasedimentary rocks is too small to be represented on Figure 5.1.

Granitic and Other Archean Intrusions

Three or four lithologically, temporally and/or spatially distinct granitoids are present in the field area. The Carlton Lake pluton is a hornblende ± biotite tonalite to granodiorite intrusion temporally associated with the Kamiskotia Gabbroic Complex (*see* "Kamiskotia Gabbroic Complex). This pluton occupies 30 to 35 km^2 in the western half of the map area that straddles the Denton–Carscallen township boundary.

To the south of the metavolcanic rocks and the Porcupine–Destor deformation zone *(see Figure 5.1)* are granitoid rocks displaying 3 distinct characteristics:

1. To the north is a package that extends approximately 2 km south from the mylonite zone. This unit is a moderately foliated, hornblende granodiorite to tonalite that resembles the Carlton Lake pluton and may be associated with it.
2. South of the unit described above is a penetratively foliated to gneissic, potassium feldspar megacrystic biotite ± muscovite granite. No intrusive relationships were observed which could offer relative age criteria between the aforementioned felsic intrusives.
3. A yellow or cream weathering, foliated, biotite-muscovite granodiorite to granite intrudes the porphyritic granite and is located in the southernmost section of the map area.

Proterozoic Dikes

Weakly magnetic diabase dikes of the Paleoproterozoic Matachewan dike swarm intrude all of the above rock units. These dominantly north-northwest-trending dikes are largely undeformed, unmetamorphosed and unaltered. Rare, small offshoots from these large, commonly plagioclase-porphyritic dikes intrude as subconcordant sills over short distances. One highly magnetic, northwest-trending, Mesoproterozoic Sudbury dike is interpreted (from aeromagnetic data) to cut the northeast corner of Carscallen Township (OGS 2001).

STRUCTURE

The impacts of 4 deformational episodes have been recognized in the map area. D_1, the earliest episode of deformation, is most pervasively developed in metavolcanic rocks of the Deloro and Tisdale assemblages. D_1 is manifested as a penetrative foliation (S_1) and rare, tight to isoclinal folds (F_1) (Photo 5.1a). Meso-scale F_1 folds are rootless and display an axial planar foliation. These folds are rare or difficult to discern as they typically occur in rocks lacking planar inhomogeneities (i.e., bedding). D_2 features include a foliation (S_2) and tight to close folds (F_2) (Photo 5.1b). F_2 folds are typically asymmetrical (usually Z-shaped) and are easily recognizable since they fold the S_1 foliation. Typically, S_1 and S_2 form a composite foliation, but they become subparallel to oblique at or near the closures of F_2 folds. Where the composite S_1 and S_2 cleavages are subparallel, S_2 is typically more obvious on the weathered surface of an outcrop while S_1 is the more penetrative foliation. A set of crenulations (F_3) can be observed on S_1 and S_2 surfaces, especially in highly sericitized and chloritized rocks (Photo 5.1c). The hinges of these crenulations are near horizontal. F_3 locally occurs as a conjugate set. D_4 is represented by conjugate kink sets with steeply dipping hinges and near vertical axial planes. These F_4 kinks can be distinguished from F_2 minor folds by the absence of an axial planar foliation, by their more solitary nature, and by the rare of conjugate sets (Photo 5.1d).

Two parallel, west-trending zones of mylonitized rocks cut the eastern half of southern Denton Township (*see* Figure 5.1). A wide, northwest-trending mylonite zone joins the southerly mylonite zone to the northerly zone. The southern zone is truncated and the northerly zone becomes wider where the northwest-trending zone intercepts it. The 2 fault zones are amalgamated into 1 zone in the western part of the township. The widest exposed section of mylonite is in the amalgamated zone where it is nearly half a kilometre wide across strike. The mylonite zones are interpreted to be the result of at least one of the deformation episodes that are included within the protracted deformational history of the Porcupine–Destor deformation zone.

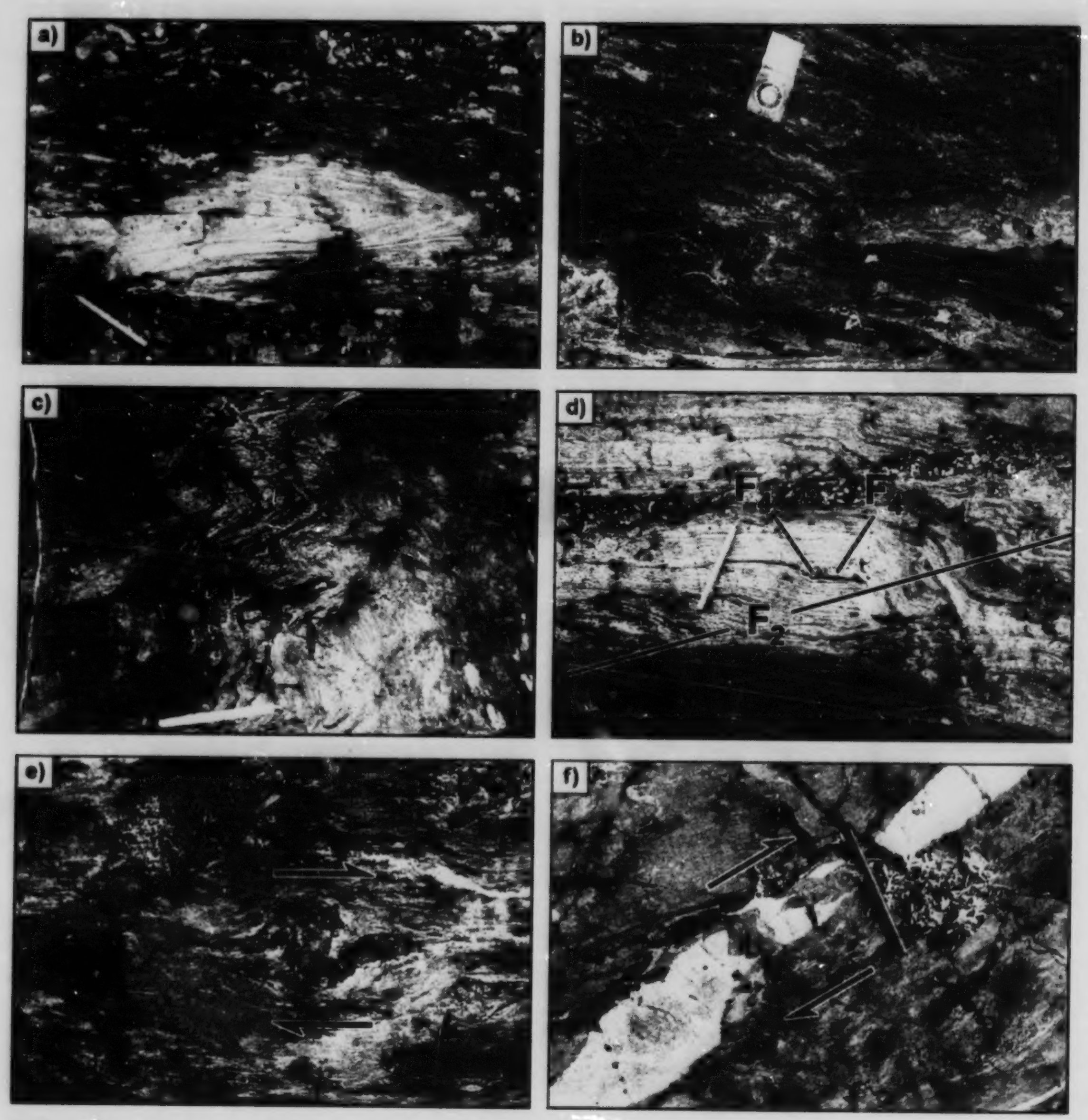

Photo 5.1. a) F_1 fold closure in Tisdale assemblage mafic metavolcanic rocks; b) F_2 fold of S_1 foliation in Deloro assemblage mafic metavolcanic rocks; c) large F_3 crenulations of S_1-S_2 composite foliation in Tisdale assemblage mafic metavolcanic rocks (view of vertical face); d) composite F_4 kink set overprinting F_2 fold in Tisdale assemblage mafic metavolcanic rocks; e) folded anisotropy showing dextral sense of shear; f) folded and boudinaged granitic dike. Pen magnet pointing north for scale in all photos.

The mylonite zones contain intimately interleaved rock units consisting of amphibolites and chlorite-feldspar rocks. Coarse-grained gabbros can be traced into the mylonitic amphibolites through a progression of grain size reduction and planar fabric development. The chlorite-feldspar rocks (dubbed the pink and green mylonite) are tentatively correlated to the epiclastic metasediments associated with the Tisdale metavolcanic rocks in the vicinity of the Godon lakes. Geochemical and petrographic analysis will be used to test this correlation. In the southern zone, east of the amalgamated zone, interpreted mafic metavolcanic rocks accompany deformed gabbros within the mylonite.

Folded anisotropies (Photo 5.1e), boudinaged and rotated dikes, local C-S fabrics and asymmetric flow patterns about passive markers all indicate a dextral sense of shear. Stretching lineations are typically shallowly west-plunging.

Granitoid dikes of 2 different characters and relative ages cut the rocks within the mylonite zones. An early suite of tonalitic to granodioritic dikes lies within the main mylonitic fabric. It is interpreted herein that these dikes were intruded prior to the episode of high strain that created the fabric. A later suite of granitic dikes transects the mylonitic fabric, but also exhibit a moderately well-developed fabric. The dikes are folded and boudinaged within the shear zone (Photo 5.1f). These observations indicate that these late dikes intruded during mylonite development. A sample taken from one the later granitic dikes was collected for U/Pb zircon geochronology. It is hoped that the age obtained from this sample will help to constrain one of the episodes of deformation that resulted in the development of the Porcupine–Destor deformation zone.

The mylonite zones are interpreted to be temporally associated with the D_2 deformation in the rocks to the north of the zones. The absence of overprinting F_2 folds suggests that this fabric must have developed either syn- or post-D_2. The dominant Z-asymmetry of F_2 folds supports a dextral transcurrent regime. The absence of overprinting D_3 crenulations would suggest that the mylonitic fabric was not present during D_3. The non-ubiquitous nature of F_3, however, renders this argument less compelling. A set of northwest-trending fractures overprinting the mylonitic fabric is correlated with D_4. It should be noted, however, that these associations have yet to be tested by petrographic examination and stereonet analysis of the abundant structural data collected.

A late, north-striking fault transects the rocks near the western margin of the map area (*see* Figure 5.1). A 2 km, sinistral offset of lithological contacts and the Porcupine–Destor deformation zone is observed across this fault. It is interpreted to be genetically related to the Mattagami River fault.

MINERALIZATION AND ALTERATION

Numerous mineral properties are situated in Carscallen and Denton townships (*see* Figure 5.1). The majority of these are gold properties that have been sporadically investigated for several decades. Gold mineralization is associated with a diversity of rock types, assemblages, structures and alteration characteristics in the map area. Table 5.1 summarizes the geological characteristics of the gold properties indicated on Figure 5.1. Some of the general characteristics of gold properties in the map area are as follows:

- host rocks include metavolcanic rocks, iron formation and granodioritic rocks of the Carlton Lake pluton
- wall rock alteration dominantly consists of chloritization, silicification and variable late carbonatization
- gold is commonly associated with sulphide minerals such as pyrite and arsenopyrite
- gold occurs with disseminated sulphide mineralization and quartz-carbonate or quartz-chlorite veins that may or may not be deformed
- gold is hosted by D_2 and D_3 structures, such as folds, shear zones and late brittle faults

Table 5.1. Summary of characteristics of gold properties in Denton and Carscallen townships.

Occurrence Name	Host Lithology	Local Structures	Mineralization Type	Associated Minerals	Wall Rock Alteration
1. Wire Gold	Deloro banded iron formation	Brittle faults and associated quartz-calcite veins	Wire gold in quartz-calcite veins Iron formation	Sulphide horizons	
2. Jowsey	Carlton Lake pluton cut by porphyry dikes	Variably striking brittle faults cutting porphyry dikes and granodiorite	Massive to stringer sulphides with quartz-chlorite veins	pyrite arsenopyrite	silicification sulphidation chloritization
3. Aumo (A)	Carlton Lake pluton cut by porphyry dikes	Variably striking brittle faults cutting porphyry dikes and granodiorite	Massive to stringer sulphides with quartz-chlorite veins	pyrite arsenopyrite molybdenite	silicification sulphidation chloritization
4. Aumo (B)	Deloro assemblage metavolcanic rocks and iron formation	Very penetrative east-striking shear zone	Massive, stringer and disseminated sulphide minerals	pyrite sphalerite arsenopyrite	silicification sulphidation
5 Gowest	Tisdale assemblage komatiites	East-striking shear zone associated with PDDZ	Disseminated to stringer sulphide minerals	pyrite arsenopyrite	serpentinization carbonatization (calcite)
6. Cameco	Tisdale assemblage komatiites	Very penetrative foliation and F_2 folds	Quartz veins associated with F_2 fold closures; Disseminated sulphide minerals	pyrite arsenopyrite	iron carbonatization
7. Wakemac	Tisdale/Deloro? assemblage mafic metavolcanic rocks	Very penetrative foliation and F_2 and F_3 folds; shear zones	Massive to disseminated sulphide minerals	pyrite arsenopyrite	iron carbonatization

Abbreviation: PDDZ, Porcupine–Destor deformation zone

The confirmed presence of Kidd–Munro assemblage FIIIb-type rhyolites (Ayer et al. 1999) in northern Carscallen Township has kindled an interest in exploration for volcanogenic massive sulphide (VMS) deposits in the map area. The Deloro assemblage iron formations (*see* Figure 5.1) are also being reassessed for their copper-zinc potential.

Magmatic sulphide mineralization in the Kamiskotia Gabbroic Complex (*see* Figure 5.1, occurrence 8), in the form of net-textured chalcopyrite and pyrrhotite, contain elevated nickel and copper values, but lack significant enrichment in platinum group elements (PGEs) (Barrie 1992). In eastern Denton Township, a sample from a small, highly strained gabbro exposure (*see* Figure 5.1, occurrence 9) yielded elevated Pt (26 ppm) and Pd (19 ppm) levels (*see also* Choudhry 1989, Table 2, sample 81AGC-0125).

RECOMMENDATIONS

Mining activities have yet to be conducted in Carscallen and Denton townships. However, many of the rocks in the area are correlated with rock units that host numerous gold deposits and volcanogenic massive sulphide deposits outside the present map area. The presence of Tisdale assemblage mafic to ultramafic metavolcanic rocks in proximity to Porcupine metasedimentary assemblage rocks, north of the Porcupine–Destor deformation zone, makes the area in the vicinity of Mahoney Creek in Denton Township a good target for gold exploration (*see* Figure 5.1). Historically, anomalous gold values have been found in this area. Anomalous gold and copper values have been reported (L. Bonhomme, written communication, 2001) in association with the iron formations of the Deloro assemblage in Carscallen Township. The confirmed presence of Kidd–Munro felsic metavolcanic rocks (Ayer et al. 1999) correlated across northern Carscallen Township makes the area a good prospect for volcanogenic massive sulphide mineralization. Much of the map area is currently staked and a great deal of work is on-going on these claims.

The structural complexity, economically significant rock types and unusual geologic map-pattern in Carscallen and Denton townships warrant further investigation. The lithological and structural mapping conducted across these townships this summer has led to the unravelling of some of the complexities and has helped to delineate the relative positions of the assemblages. Examination of diamond-drill core has assisted this process by filling in some of the sizeable holes in the exposure. Further examination of diamond-drill core, assessment files and geophysics, coupled with lithogeochemical analytical results and petrographic examination of the rock types and structures, will help refine and expand on the interpretation of the geology.

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6. Project Units 97-013 and 00-011. Structural Style and Kinematics of the Porcupine–Destor Deformation Zone, Abitibi Greenstone Belt, Ontario

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INTRODUCTION

The Porcupine–Destor deformation zone (PDDZ) is one of the principal regional structural lineaments within the Abitibi greenstone belt. In Ontario, the strike length of a continuous segment of the PDDZ is over 200 km, from the Matagami River fault (southwest of Timmins) to the border with the province of Quebec. The Matagami River fault crosscuts and offsets the PDDZ, which continues further to the west, into the Swayze greenstone belt (Ayer and Trowell, this volume, Figure 4.1). The strike of the PDDZ in Ontario is generally east, except in Hislop and Guibord townships, where the map trace trends northwest. Several fault splays of the PDDZ have been identified in the Hislop and Guibord townships area (Ayer, Berger and Trowell 1999; Berger 1999). The deformation history of the PDDZ in Ontario and the kinematics of displacements that were accommodated by the PDDZ are not well documented or understood. The continuation of the PDDZ in Quebec has a northeast strike. Structural analysis of the Quebec segment indicates that the PDDZ accommodated primarily strike-slip displacements, as demonstrated by the presence of a shallow-plunging extension lineation and dextral shear-sense indicators (Mueller et al. 1996).

In the course of recent and on-going bedrock mapping and structural analyses of the PDDZ, it has become apparent that the deformation style (generations, orientations and geometries of structures) and the kinematics of deformation within the PDDZ are quite similar along much of its strike length in Ontario. The structural geology of the rocks is very comparable in the studied regions, including Ogden Township (southwest of Timmins) and in several townships between the village of Matheson and the Ontario–Quebec provincial border.

This contribution aims to synthesize some new geological data gathered during field work and petrographic studies: 1) to highlight the important, widely occurring structural features of the PDDZ; and 2) to serve as a basis for further analysis of the deformational history of that first-order, regional-scale structure. Our data should also be of interest to mineral exploration programs since the PDDZ (and splays of the PDDZ) represent loci for gold deposits that are often "structurally controlled" (i.e., the genesis and geometries of gold deposits are directly related to the structural geology of the host rocks). Furthermore, it is important to unravel the structural evolution of the PDDZ to better constrain models for the tectonic evolution of the Abitibi greenstone belt.

OVERVIEW OF THE PORCUPINE–DESTOR DEFORMATION ZONE

In the Ontario portion of the Abitibi greenstone belt, the PDDZ is a sinuous, broadly east-striking zone of strong shearing and faulting, probably made up of overlapping anastomosing segments, with an overall strike length of several hundred kilometres. At its western extent, a continuous segment of the PDDZ terminates against the north-striking Matagami River fault, in Ogden Township. The PDDZ has a finite thickness that varies within the hectometre to kilometre scales. The deformed rocks within the PDDZ include predominantly metavolcanic and metasedimentary rocks belonging to several recently redefined lithotectonic assemblages (Ayer et al. 1999). Lithotectonic assemblages in Ogden Township include 1) ultramafic to felsic metavolcanic rocks and minor amounts of metamorphosed iron formation, belonging to the Deloro (2730 to 2724 Ma), Kidd–Munro (2719 to 2711 Ma) and Tisdale (2710 to 2703 Ma) assemblages; and 2) turbiditic metasedimentary rocks of the Porcupine assemblage which unconformably overly the metavolcanic assemblages (maximum depositional age of 2698 to 2696 Ma) (Ayer et al. 1999; Bleeker and Parrish 1996). In the region east of Matheson, the deformed rocks include the Tisdale and Kidd–Munro assemblages; the Porcupine assemblage; and conglomerates and sandstones of the Timiskaming assemblage (2685 to 2675 Ma) which unconformably overlie the older assemblages (Ayer, Berger and Trowell 1999; Ayer et al. 1999). In the Abitibi greenstone belt, the Timiskaming assemblage has an intimate spatial association with linear deformation zones like the PDDZ. Tectonic models have attempted to explain the spatial relationship as the result of deposition of Timiskaming assemblage rocks within elongate basins associated with normal (Dimroth et al. 1983a, 1983b) or transcurrent (Mueller et al. 1996) faults.

The structure of the PDDZ, as outlined here, is based on 1:20 000 scale bedrock mapping of Holloway, Harker, Guibord, Michaud, Garrison and Hislop townships (Berger and Amelin 1998; Berger 1997, 1999); detailed structural studies of underground workings and the surface geology of mine properties in Holloway Township (Luinstra and Benn 1997, 1999, 2001); investigations of diamond-drill cores from Garrison and Michaud townships (K. Benn, University of Ottawa, unpublished data, 2000); and 1:20 000 scale bedrock mapping of Ogden Township (Vaillancourt 2000). Mapping in Ogden Township was complemented by a detailed structural analysis of properties belonging to Echo Bay Mines Ltd. and International Falcon Resources Ltd. (Dinel and Benn 2000; Dinel 2001).

STRUCTURAL GEOLOGY OF THE PORCUPINE–DESTOR DEFORMATION ZONE

Three distinct generations of structures have been identified within the PDDZ in underground mine workings, in outcrop and in diamond-drill cores. The 3 generations of structures have also been studied in thin section in order to confirm the relative timing relationships of the fabrics with metamorphism and alteration events; and to confirm the kinematics of the deformation. All 3 generations of structures have affected the youngest supracrustal rocks—the Timiskaming assemblage—therefore, the deformation events recorded by the structures must postdate deposition of the Timiskaming assemblage rocks. In the following paragraphs, we will describe the style of each generation of structures and present evidence for the kinematics of deformation where appropriate. Equal-area lower hemisphere projections of structural elements measured in Ogden and Holloway townships, which are separated by approximately 150 km strike length of the PDDZ, show very similar orientations at those 2 widely spaced localities (Figures 6.1 and 6.2). Interpretations of the significance of the structural geology of the PDDZ, in light of the regional geology and available geochronological data, will be discussed below (*see* "Discussion").

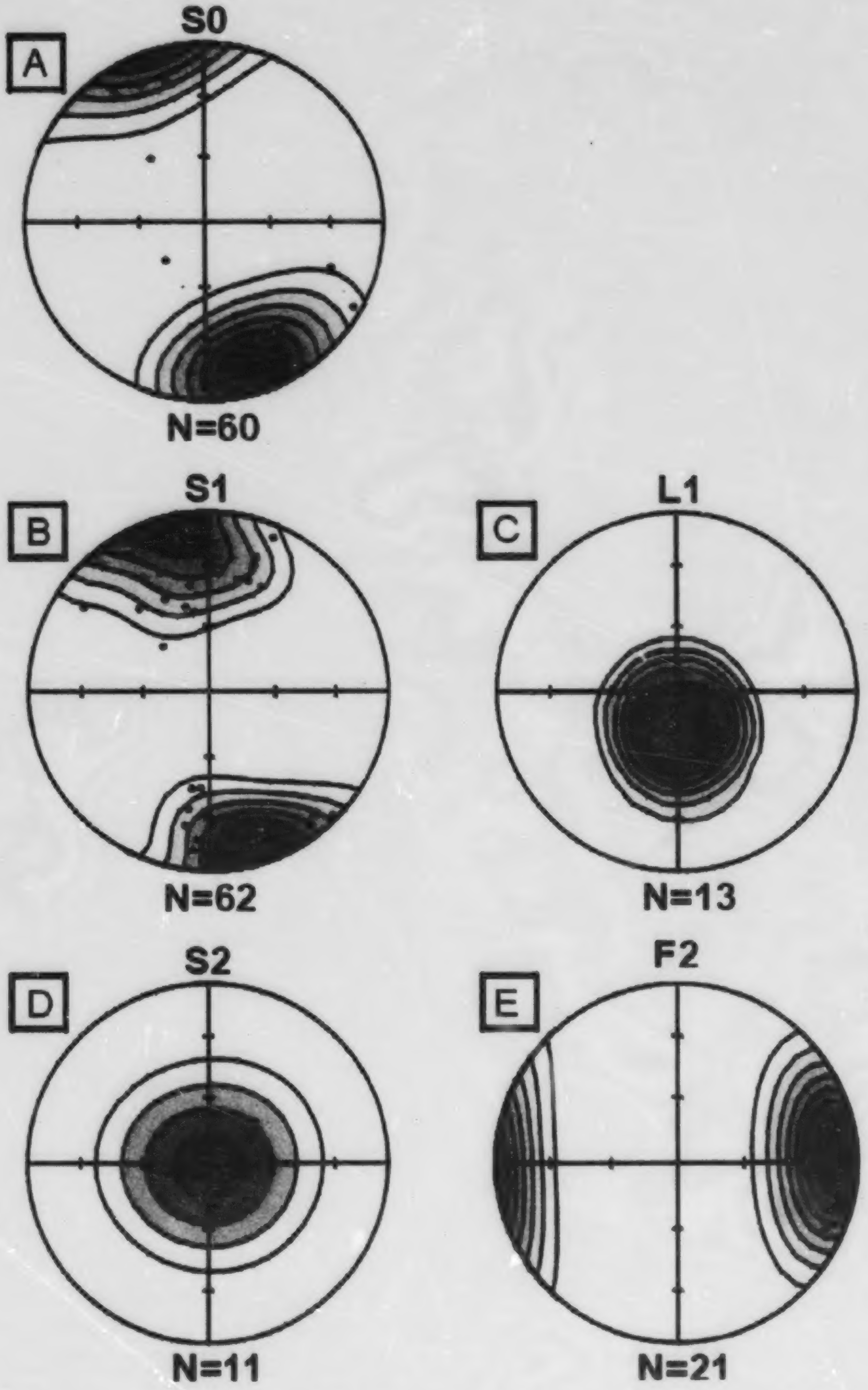

Figure 6.1. Equal-area lower hemisphere projections of the principal structural elements measured in the Holloway Mine, Holloway Township: **A)** poles to S_0 (bedding); **B)** poles to S_1 foliation; **C)** L_1 extension lineation; **D)** poles to S_2 foliation; and **E)** F_2 fold axes.

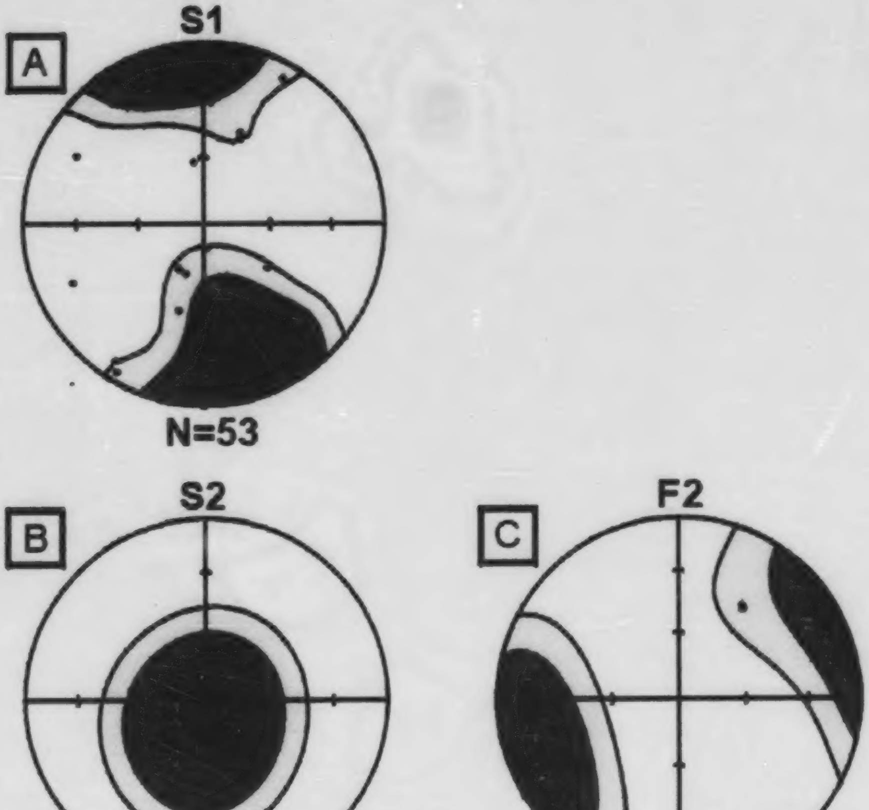

Figure 6.2. Equal-area lower hemisphere projections of the principal structural elements measured in Ogden Township: **A)** poles to S_1 foliation; **B)** poles to S_2 foliation; **C)** F_2 fold axes; **D)** poles to S_3 foliation; and **E)** F_3 fold axes.

D_1 Structures

The D_1 structures include upright, steeply plunging isoclinal F_1 folds, a penetrative S_1 foliation and an L_1 extension lineation within the S_1 plane. F_1 folding has resulted in the transposition of rock units, and their internal layering parallel to the S_1 foliation. Transposition is demonstrated by the parallel orientations of primary structures such as S_0 (bedding) and S_1 (Figures 6.1A and 6.1B).

F_1 FOLDS

Because of the severe transposition of primary structures during D_1, it is likely that many, or most, of the F_1 folds are rootless (i.e., their hinges are isolated from their highly attenuated limbs). Hence, recognition of F_1 folds depends on the identification of fold hinges in outcrop, and on the documentation of changes in polarity as provided by primary "top" indicators (i.e., pillowed flows, cross-bedding, graded bedding). In Ogden Township, a steeply plunging F_1 fold hinge is documented in banded iron formation (*see also* Dinel and Benn 2000, Figure 12.1b). In Holloway Township, the observation of a north-striking, steeply dipping contact between 2 metavolcanic flows of the Kidd–Munro assemblage, perpendicular to the S_1 foliation, suggests the presence of another steeply plunging F_1 fold (Photo 6.1A). Top indicators have been used to interpret the locations of axial surfaces of isoclinal F_1 folds within the Holloway gold mine (*see also* Luinstra and Benn 2001, Figure 4.1). The recognition that primary structures in the metavolcanic and metasedimentary rocks within the PDDZ are transposed parallel to S_1 is of critical importance to any attempt to document stratigraphic relationships and the original thicknesses of rock units within the deformation zone.

S_1 FOLIATION

In outcrop, the S_1 foliation is very strongly developed, and the presence of severely deformed veins indicates that a high degree of shortening occurred perpendicular to the S_1 foliation (Photo 6.1B). Abundant veins composed of quartz and carbonate minerals have been transposed parallel to S_1 and, in outcrop, the transposed and boudinaged veins provide an easily recognizable expression of the S_1 foliation (*see* Photo 6.1B).

The composition of many of the rocks within the PDDZ, particularly the ultramafic and mafic metavolcanic rocks, have been very heavily modified during several alteration events, resulting in the presence of abundant calcite. In thin section, the S_1 foliation often has a disjunctive morphology (Twiss and Moores 1992) with narrow chlorite-rich cleavage domains separated by calcite-rich microlithons that are 1 mm or less in thickness (Photo 6.1C). Numerous observations, made in outcrops, in diamond-drill cores, and in thin sections, suggest that many and possibly all of the calcite-rich microlithon domains are the result of shearing, folding, boudinage and the transposition of veins parallel to S_1. Commonly, different generations of veins are present: older veins have undergone greater strain and transposition, while younger veins remain discordant to S_1. An extreme example is shown in Photo 6.1D where older S_1-parallel (transposed) veins are crosscut by perpendicular younger veins that have undergone minor shortening. Photo 6.1E shows an example of isoclinally folded quartz-calcite veins with locally attenuated limbs. Photo 6.1F is a photomicrograph that shows folded veins (similar to those in Photo 6.1E) and thin chlorite-rich bands, defining S_1, that are folded with the veins. This observation strongly suggests that the foliation has, at least locally, been folded and transposed several times during a progressive D_1 deformation.

In most of the regions where we have studied the PDDZ, the S_1 foliation dips steeply (>60°) to the north or to the south (*see* Figures 6.1B and 6.2A), though in Taylor Township, the dip of the foliation is relatively shallow, approximately 45° to the south.

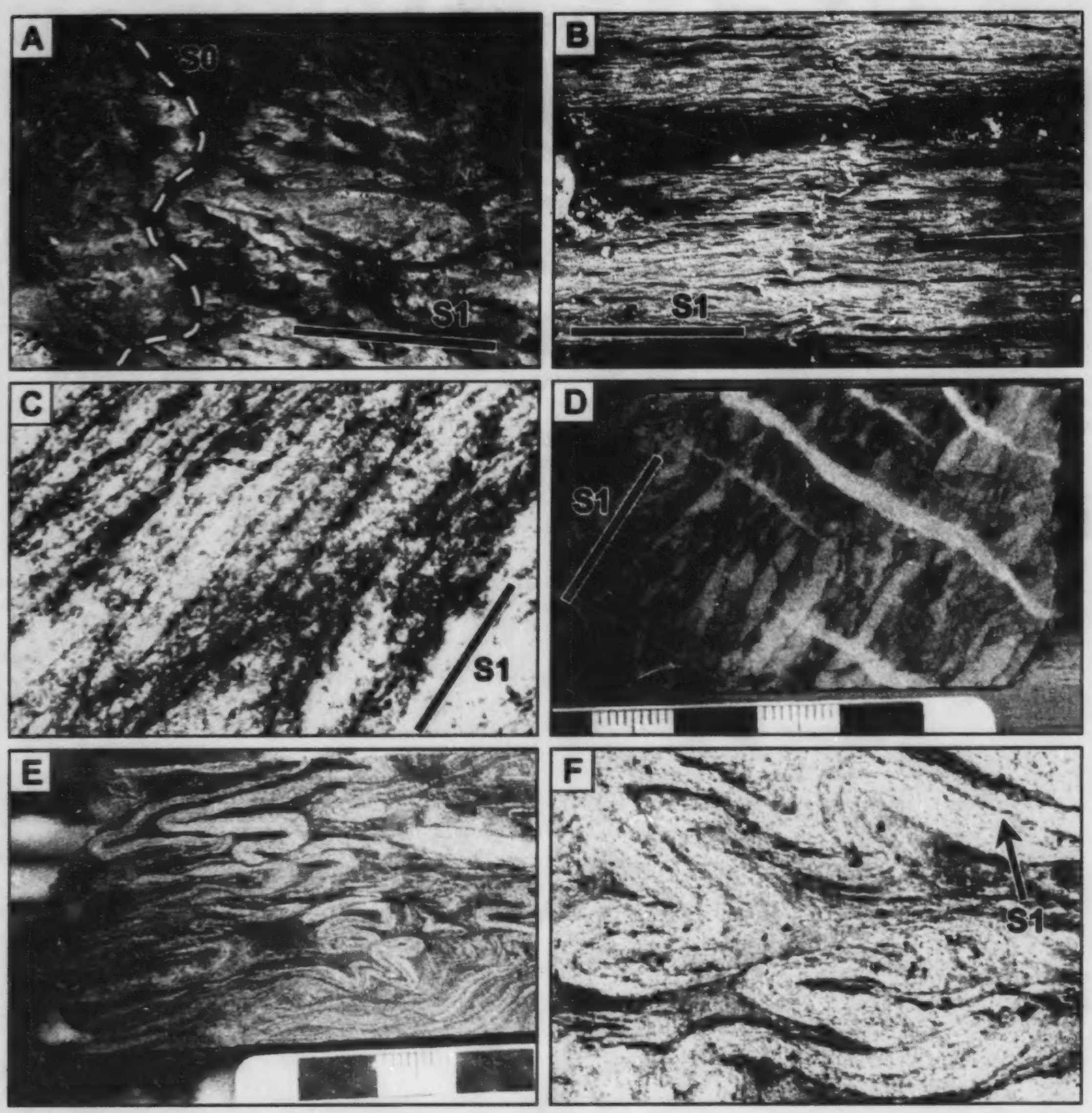

Photo 6.1. **A)** F_1 fold hinge zone in ultramafic volcanic rocks, indicated by the perpendicular orientations of S_1 (flattened pillows) and S_0 (flow top), Holloway Township. **B)** S_1 foliation in ultramafic volcanic rocks, Ogden Township. Note the severely shortened north-striking quartz vein. **C)** Photomicrograph of S_1 foliation, plane polarized light. The lighter domains are made up mainly of transposed calcite-rich veins. Horizontal dimension of photo is 1 cm. **D)** S_1 foliation defined by transposed and boudinaged calcite-rich veins, viewed in a split diamond-drill core. The calcite-rich extensional veins are perpendicular to S_1. Scale on card is in centimetres. **E)** F_1 folds of calcite-rich veins, viewed in split diamond-drill core. Scale on card is in centimetres. **F)** Photomicrograph of F_1 folds of calcite-rich veins. The S_1 foliation (dark bands) is also folded indicating that D_1 involved repeated transposition of S_1. Horizontal dimension of photo is 3 cm.

L_1 LINEATION

The L_1 extension lineations are defined by stretched clots of chlorite (Photo 6.2A); by elongate aggregates of calcite and quartz (Photo 6.2B); and by pressure shadows attached to crystals of opaque minerals such as pyrite (Photo 6.2C; *see also* Luinstra and Benn 2001, Figure 4.5). The L_1 lineation is generally parallel to the dip direction of the S_1 foliation (*see* Figure 6.1C).

KINEMATICS OF D_1 DEFORMATION

The sense of shear associated with S_1 development is determined from the asymmetries of pressure shadows attached to pyrite grains (*see* Photo 6.2C; *see also* Luinstra and Benn 2001, Figure 4.4); from asymmetrically folded and sheared quartz-carbonate veins observed in diamond-drill core, outcrop, underground workings and thin section (Photos 6.2D and 6.2E); and from the deflections of the S_1 foliation in proximity to sheared veins (*see* Photos 6.2D and 6.2E). In the vast majority of cases, the sense of shear associated with D_1, as determined from those indicators, is south-side-up, irrespective of the sense of dip or the dip angle of the S_1 foliation.

The D_1 deformation resulted in the development of isoclinal F_1 folds, therefore, the determination of the D_1 shear sense, based on mesoscopic- and microscopic-scale structural asymmetries, must be considered with some caution. Small-scale structures could conceivably record only a local shear sense on the limbs of S_1 folds, assuming folding involved flexural shearing of the rock units. However, the predominance of south-side-up indicators strongly suggests that this corresponds to the non-coaxial component of the bulk shearing within the PDDZ during D_1.

D_2 Structures

The spatial distribution of D_2 structures is extremely heterogeneous. At the outcrop scale, the development of D_2 structures was locally controlled by the presence of rheological heterogeneities in the rocks, such as quartz veins or lithologic contacts. Localization of D_2 structures may also have been controlled by the presence of heterogeneities at larger scales. For instance, within the Holloway Mine, F_2 folds may have nucleated on relatively stiff (silicified and albitized) ore zones that are hosted by more ductile rocks (Luinstra and Benn 2001).

F_2 FOLDS

The pervasive D_1 structures are deformed by shallow-dipping F_2 folds. The dips of the axial surfaces of the F_2 folds are rarely greater than 30° (*see* Figures 6.1D and 6.2B). The trends of the shallow-plunging F_2 folds are east to east-northeast and the shallow plunges are either to the east or west (*see* Figures 6.1E and 6.2C). The F_2 folds occur at a wide range of scales from microscopic crenulations (Photo 6.3A) to hectometre-scale folds, observed, for example, in the Bianchi Quarry in Ogden Township (Photo 6.3B), and in the Holloway Mine, where F_2 folds deform the orebodies (*see also* Luinstra and Benn 2001, Figure 3.2).

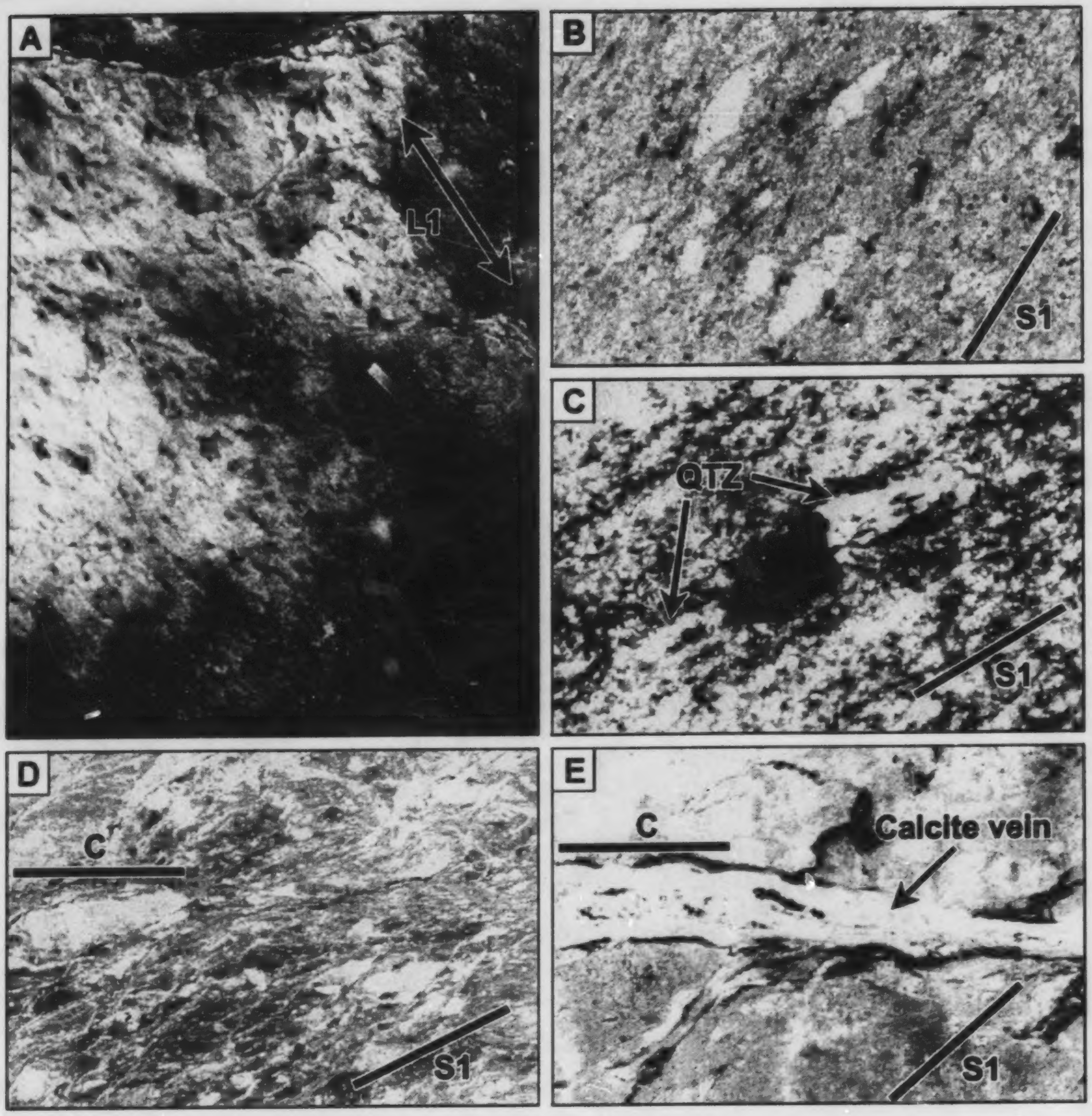

Photo 6.2. **A)** L_1 extension lineation defined by stretched, dark coloured chlorite-rich clots; **B)** Photomicrograph of L_1 extension lineation defined by stretched quartz aggregates, viewed in the plane perpendicular to S_1 and parallel to L_1. The horizontal dimension of the photo is 1 cm; **C)** Photomicrograph of quartz-filled pressure shadows attached to a pyrite crystal. The pressure shadows define L_1 and their asymmetry indicates dextral shear in the photo (south-over-north in geographic coordinates). Horizontal dimension of the photo is 1 cm. **D)** Photomicrograph of a shear band (probable C-plane) oblique to S_1, indicating dextral shear in the photo (south-over-north in geographic coordinates). Horizontal dimension of the photo is 1 cm. **E)** Photomicrograph of a shear band (probable C-plane) filled with a calcite vein, and oblique to S_1, indicating dextral shear in the photo (south-over-north in geographic coordinates). S_1 is also deflected in a dextral sense near to the shear band margins. Horizontal dimension of the photo is 1 cm.

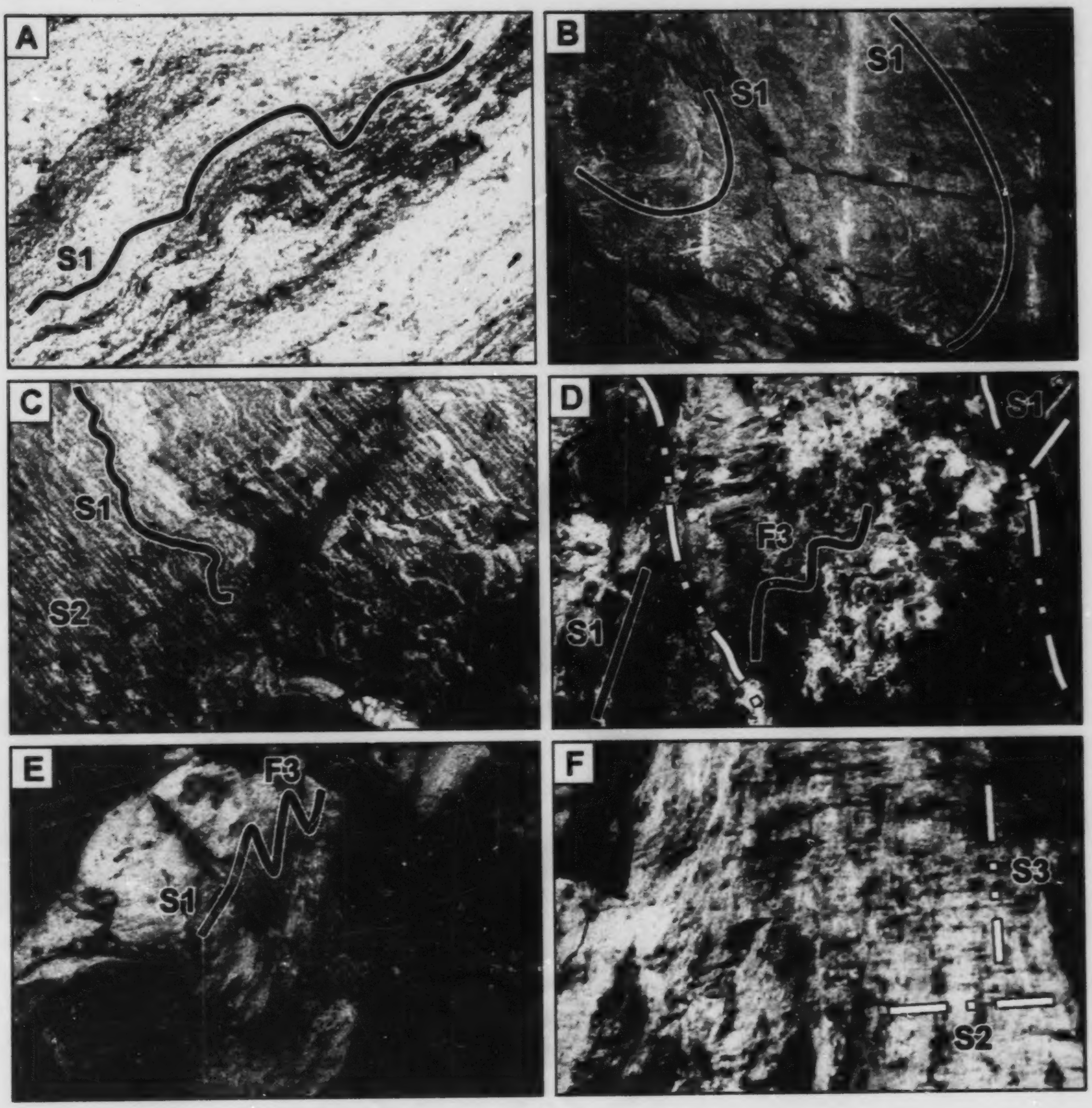

Photo 6.3. **A)** Photomicrograph of F_2 folds that deform S_1. The fold in the centre of the photo has 2 hinges, that is, it is a box fold. Horizontal dimension of the photo is 3 cm. **B)** Vertical quarry face where an F_2 fold deforms S_1, which is defined in the photo by the transposed quartz and calcite veins (light coloured). Lens cap for scale, Ogden Township. **C)** Vertical quarry face where S_1 is folded by an F_2 fold. The photo is of the hinge zone of the F_2 fold. The shallow-dipping S_2 foliation domains are spaced by 10 to 20 cm. Horizontal dimension of the photo is approximately 2 m. **D)** Horizontal outcrop surface where a D_3 shear zone deforms S_1 into steeply plunging F_3 folds. The shear zone boundaries are highlighted by the dashed-dotted lines. Pen for scale. **E)** Angular, moderately plunging F_3 foids of the S_1 foliation, Ogden Township. Pen for scale. **F)** Vertical outcrop face where the S_2 and S_3 foliations are present. Pen for scale is located in the upper left corner of the photo.

In profile, F_2 antiforms and synforms may occur in isolation, rather than forming sinusoidal waveforms, or they may form fold trains that apparently die out over approximately one or two wavelengths (*see* Photo 6.3A). The F_2 folds are interpreted to occur within discrete tabular or lenticular bodies of rock of finite thickness (about one half-wavelength to a few wavelengths of the folds) and of restricted lateral extent. In this sense, the rock units that contain F_2 folds would resemble kink bands in their morphology. In profile, the F_2 folds are rounded to subrounded and may define box folds (i.e., folds with 2 hinges) (*see* Photo 6.3A).

S_2 FOLIATION

An S_2 axial planar disjunctive crenulation foliation is associated with the F_2 folds. The foliation domains are defined by aligned micaceous minerals, such as chlorite and opaque minerals. The S_1 foliation is preserved within microlithons (*see also* Luinstra and Benn 2001, Figure 4.5). The foliation domains may be spaced by less than 1 mm, as observed in thin section, or the spacing may be on the decimetre scale (Photo 6.3C).

The S_2 foliation is heterogeneously developed, and is very strongly expressed within highly sheared and locally attenuated limbs of F_2 folds. The S_2 foliation is also strongly developed in proximity to rigid heterogeneities, such as quartz veins within the folded rocks. Shallow-dipping shear zones and faults corresponding to highly attenuated fold limbs have accommodated D_2 displacements of centimetres to hectometres. In the Holloway Mine, the principal ore zone, the Lightning Zone, is deformed by F_2 folds and locally offset by faults developed on the fold limbs.

D_3 Structures

In localities east of the village of Matheson, the D_3 structures are expressed mainly as north-northwest- to north-northeast-striking, steeply dipping narrow ductile shear zones or brittle faults. These structures are commonly lined with chloritic gouge. Some of these structures have accommodated oblique, sinistral, east-side-down displacements (Berger 1997; Berger and Amelin 1998). In Ogden Township, the D_3 structures have a more ductile nature, typically expressed as steeply dipping, north-northwest- to north-northeast-striking shear zones up to 1 m thick (Photo 6.3D). The S_1 foliation is deformed and folded within the shear zones, forming steeply to moderately plunging F_3 folds (*see* Figure 6.2E; *see* Photos 6.3D and 6.3E), which may be either asymmetrical or symmetrical in profile. Other than brittle faults and ductile shear zones, D_3 deformation is also expressed as a locally developed S_3 crenulation foliation, similar in morphology to the S_2 foliation, but with subvertical dips (*see* Figure 6.2D). Field observations on outcrops, such as shown in Photo 6.3F, are a relatively rare occurrence where both S_2 and S_3 structures are observed at the same locality. These observations allow the determination of the relative ages of the D_2 and D_3 structures.

Doubly plunging F_3 folds have been observed in Ogden Township (*see also* Dinel and Benn 2000, Figure 12.1d) and are likely due to F_3 refolding of the S_1 foliation that was previously folded by F_2. Therefore, it should be noted that complex map patterns might be expected in regions where there is interference between D_2 and D_3 structures within the PDDZ.

DISCUSSION

The structural geology of the rocks within the PDDZ in Ontario is remarkably similar along 200 km of strike length. The 3 generations of structures described above have been documented in underground workings, in outcrops, in diamond-drill cores and in thin sections from several townships east of the village of Matheson and as far west as Ogden Township, southwest of Timmins. We will now briefly survey some implications of our data and observations for the tectonic evolution of the Abitibi greenstone belt and for mineral exploration within the PDDZ and its associated splay structures.

Implications for Tectonic Models

A key observation is that all 3 generations of structures documented here have affected the youngest lithotectonic assemblage within the PDDZ, the conglomerates and sandstones of the Timiskaming assemblage (2685 to 2675 Ma). The tectonic event(s), which gave rise to the D_1, D_2 and D_3 structures, deformed a stratigraphic package that contains 2 unconformities: the first unconformity underlying the Porcupine assemblage, indicating tilting of the underlying rocks at approximately 2698 Ma (the crystallization age of rhyolitic rocks that underlie the unconformity) (Bleeker and Parrish 1996); and a second unconformity underlying the Timiskaming assemblage. Therefore, the structures documented in this work record tectonics that postdate the events that tilted rocks in the Abitibi greenstone belt. The spatial association of the linear outcrop pattern of Timiskaming assemblage rocks with regional-scale deformation zones, such as the PDDZ, suggests that the Timiskaming depositional basins may have formed in association with early displacements on the deformation zones. These deformation zones may have been active as extensional basin-bounding fault zones (Dimroth et al. 1983a, 1983b) or as transcurrent fault zones with associated pull-apart basins (Mueller and Donaldson 1992). D_1 deformation, which records regional, broadly north–south shortening of the Abitibi greenstone belt, would have resulted in inversion of the sedimentary basins and an apparent strong partitioning of strain into pre-existing fault zones such as the PDDZ.

At the scale of the Ontario portion of the Abitibi greenstone belt, the principal structural features that control the outcrop patterns are broad east-trending anticlines and synclines, such as the Blake River syncline that occupies much of the region south of the PDDZ and north of the Larder–Cadillac deformation zone. Numerous other folds with orientations parallel to regional deformation zones occur north and south of the PDDZ (Ayer, Berger and Trowell 1999). Where the PDDZ has a northwest orientation, such as in Hislop and Guibord townships, the axial surface traces of the folds have a similar orientation. The parallelism between F_1 folds and the east-striking deformation zones suggests that the shortening accommodated by the folds records the same event as the strong D_1 deformation within the PDDZ. Polarity indicators within the metavolcanic and metasedimentary rocks indicate that F_1 folds are true anticlines and synclines, and consistent facing directions within the regional folds suggest this was the first major regional folding event to affect the Abitibi greenstone belt. Fold interference patterns possibly associated with D_1 deformation (e.g., south of the Lake Abitibi batholith) may be restricted to distinct areas, and would have resulted, in one interpretation, from the interference of folds formed in proximity to growing batholithic intrusions, and, in another interpretation, from the interference of the regional east-trending F_1 anticlines and synclines. The D_1 deformation within the PDDZ can therefore be confidently correlated with the generation of regional east-trending folds and, therefore, with the inversion of the Abitibi basin resulting from the north to south shortening event which occurred after deposition of the Timiskaming assemblage.

Structural Geology and Deformation of Ore Deposits

The S_1 foliation and L_1 extension lineation are documented within ore zones in the Holloway Mine (Luinstra and Benn 2001). Therefore, the orebodies must have formed either prior to or during the D_1 deformation event. Hence, known and potential orebodies within the PDDZ may have been affected by 3 deformation events which may have controlled or significantly modified their geometries and their spatial distribution. In the Holloway Mine, the orebodies are deformed by shallow-dipping D_2 folds and faults.

The D_2 and D_3 structures (fold hinges, shear zones, brittle-ductile and brittle faulting), which postdate formation of much of the gold mineralization within the PDDZ, would have been available to channel mineralizing hydrothermal fluids during any late mineralizing events or during remobilization of gold that may have occurred during or following D_2 and D_3 deformation. Gold mineralization is known to be associated with late structures that are considered here to be D_3 faults, for instance, in the past-producing Croesus Mine in Munro Township (Berger and Amelin 1998). Hence, it is important that gold exploration within the PDDZ and associated fault splays should take into account the possible effects of three stages of deformation on potential ore bodies.

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7. Project Unit 96-03. Geology of Burrows, Kemp and Mond Townships, Shining Tree Area, Districts of Sudbury and Timiskaming

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INTRODUCTION

This project is part of a multi-year study to re-evaluate the geology and mineral potential of the Shining Tree area, in the southern part of the Abitibi greenstone belt. It follows bedrock mapping completed in the vicinity by Johns and Amelin (1998) and Johns (1999) further south. The mapped area is bounded by latitudes 47°45′30″ to 47°51′N and longitudes 81°04′30″ to 81°27′30″W, comprising the townships of Burrows, Kemp and Mond (Figure 7.1). This area is shown on the compilation map of Pyke (1982), but was never mapped in detail.

Eleven weeks were spent during the summer of 2001 doing traverses ideally at 400 m intervals. Access within Burrows and Kemp townships was facilitated by the existence of old logging roads, lakes and streams. In Mond Township, the Grassy River and the hydro power line in the eastern part of the township provided the only easy access. Helicopter support was used in inaccessible parts of Mond Township. The area is generally flat-lying except for some, 200 m high, mounds in Mond Township that represent resistant Huronian sedimentary rocks. Half of Burrows and Kemp townships are covered with sand and marsh.

GENERAL GEOLOGY

The map area is underlain by Neoarchean Keewatin-age rocks, composed of a sequence that varies from ultramafic to felsic metavolcanic rocks. These rocks are intruded by a series of mafic to ultramafic metamorphosed sills. In southern Kemp and Mond townships, the Keewatin-age metavolcanic rocks are unconformably overlain by a sequence of clastic metasedimentary and reworked metavolcanic rocks of the Timiskaming assemblage. A granitic batholith is located in the northwest part of Burrows Township, where it intrudes Keewatin-age metavolcanic rocks (*see* Figure 7.1).

A large part of Kemp and Mond townships are covered with Proterozoic sedimentary rocks of the Huronian Supergroup. A gabbro that is Nipissing in age is located in the northern part of the area. Matachewan diabase dikes are found throughout the map area.

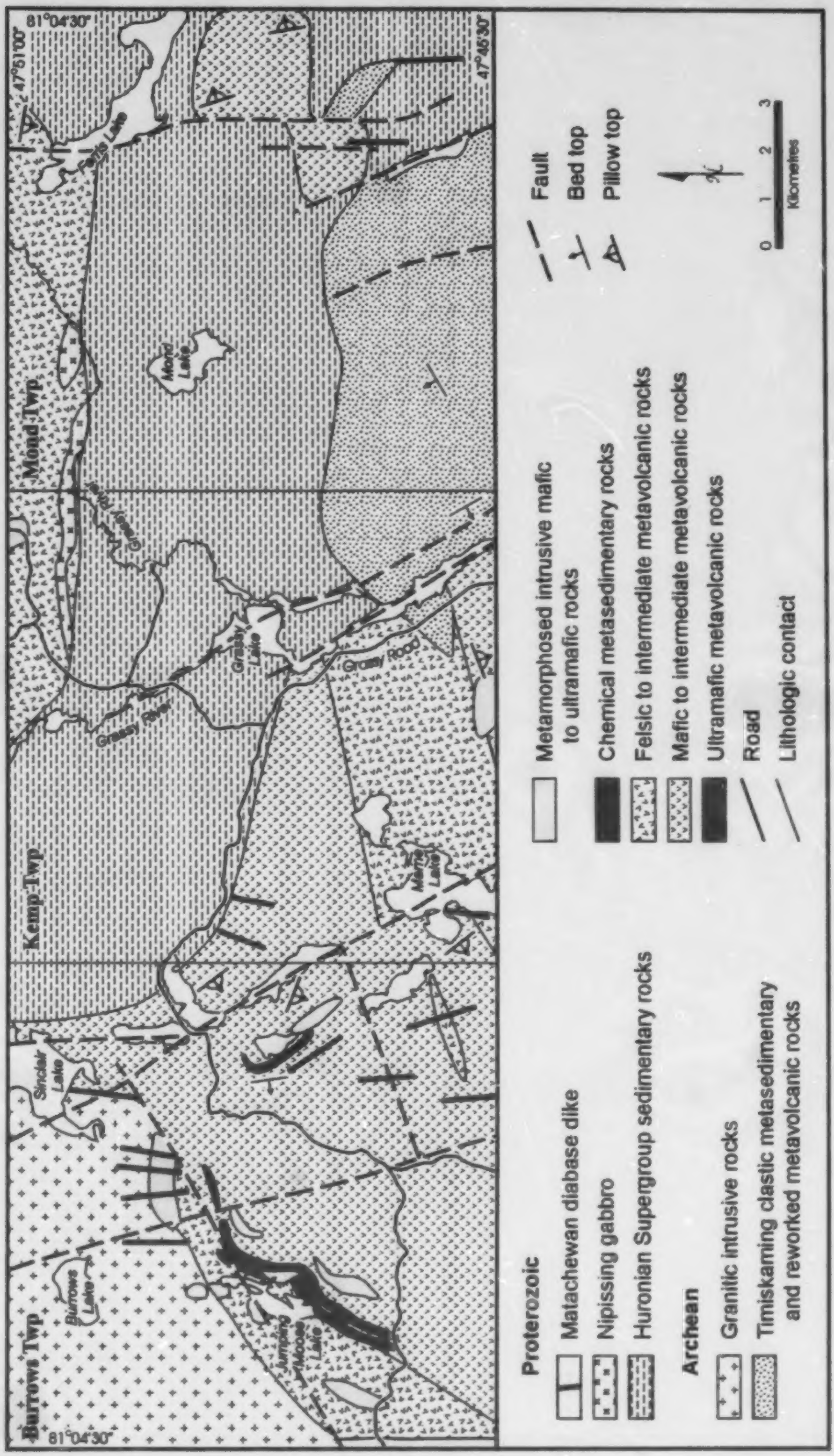
81°04'30"
81°04'30"
47°51'00"
47°45'30"
Burrows Twp
Kemp Twp
Mond Twp
Burrows Lake
Jumping Moose Lake
Sinclair Lake
Grassy River
Grassy Lake
Grassy Road
Mond Lake
Fertis Lake
Proterozoic
Matachewan diabase dike
Nipissing gabbro
Huronian Supergroup sedimentary rocks
Archean
Granitic intrusive rocks
Timiskaming clastic metasedimentary and reworked metavolcanic rocks
Metamorphosed intrusive mafic to ultramafic rocks
Chemical metasedimentary rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Ultramafic metavolcanic rocks
Road
Lithologic contact
Fault
Bed top
Pillow top
0
1
2
3
Kilometres

Figure 7.1. Simplified geology of Burrows, Kemp and Mond townships.

KEEWATIN-AGE METAVOLCANIC ROCKS

Ultramafic Metavolcanic Rocks

Two thin units of ultramafic metavolcanic rocks are found in the map area: east of Jumping Moose Lake and west of Marne Lake (*see* Figure 7.1). In the Jumping Moose area, the ultramafic rocks were observed in only 1 outcrop. The rocks are black to dark grey with no visible primary textures. All primary minerals are altered to serpentine and talc. The outcrop corresponds with a prominent magnetic anomaly (Ontario Geological Survey 1996) that can be traced for 7 km along Jumping Moose Lake. The unit has been intersected by diamond drilling (Mullen 1983). Since only 1 outcrop was observed, it is possible the unit could be an ultramafic intrusive rather than a metavolcanic rock. However, it is associated with other metavolcanic rocks and is therefore grouped with them.

The ultramafic metavolcanic rocks west of Marne Lake were not visited during this project, but were described by (Mullen 1983). Two komatiitic flows, 5 m thick, containing spinifex and cumulate zones were reported. These flows have a dark grey weathered surface and light to dark grey fresh surface. These rocks are altered to talc and chlorite and host rare pyrite. These units can also be traced on airborne geophysical magnetic maps (Ontario Geological Survey 1996) over a distance of 4 km.

Mafic to Intermediate Metavolcanic Rocks

These rocks crop out in 3 areas (*see* Figure 7.1): an extensive area encompassing most of Burrows and the middle part of Kemp townships, a smaller area south of Ferris Lake (Mond Township), and a small sliver west of Grassy Lake in Kemp Township.

In Kemp and Burrows townships, the mafic to intermediate metavolcanic rocks are commonly found as massive, pillowed and variolitic flows (Photo 7.1), pillow breccia and mafic schist. They are usually black or dark green and weather dark brown, rusty brown or dark green. They are typically aphanitic and partly silicified. Pillow width varies from 30 cm to 3 m. In general, the pillows are rounded, but, in some locations, they can be elongated. Rims of pillows are chloritized and may contain minor amounts of pyrite. Very few quartz- or carbonate-filled amygdules (millimetres in size) are found in these flows. In some areas, pods of quartz and chlorite, representing large gas cavities, are found in the middle of pillows. Variolitic (Photo 7.2) and brecciated pillowed flows are interbedded locally with massive and pillowed flows, but are not extensive. In the Jumping Moose and Marne lakes areas, the rocks are schistose due to their close proximity to fault zones. They are highly foliated and do not contain preserved primary volcanic textures. The mafic to intermediate metavolcanic rocks are probably tholeiitic basalt to calc-alkalic andesite in composition.

In the Ferris Lake area, the mafic to intermediate metavolcanic rocks occur as massive, pillowed, brecciated pillows and autoclastic breccia flows. They are dark green or black and weather brown to rusty brown. The major difference between this sequence and the one in Burrows and Kemp townships is the size of the pillows. They are, in general, larger, up to 5 m long, and contain more abundant quartz-filled amygdules. These rocks also exhibit more chlorite and carbonate alteration, as well as a higher degree of silicification. Sulphides minerals are more abundant, but are still a very minor constituent of the flows. Brecciated pillows and autoclastic breccia are found locally interbedded with massive and pillowed flows. The size of the pillows suggests a more fluid lava. Based on field observations, it is estimated that this sequence of metavolcanic rocks could range in composition from komatiitic basalt (20% of the sequence) to tholeiitic basalt and calc-alkalic andesite.

Photo 7.1. Rounded and elongated pillows in mafic to intermediate metavolcanic rocks.

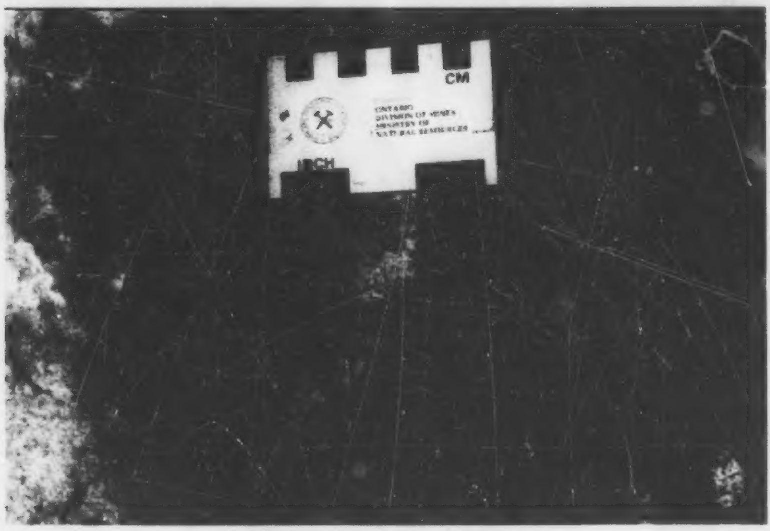

Photo 7.2. Varioles, below scale card, in mafic to intermediate metavolcanic rocks.

Felsic to Intermediate Metavolcanic Rocks

Three packages of felsic to intermediate metavolcanic rocks were found in the map area (*see* Figure 7.1). The first package of these rocks crop out in the western part of Burrows Township, the second in southern Kemp Township, and the third in northern Mond Township.

The sequence in the western part of Burrows Township is highly deformed. It is intruded by the granitic batholith and sheared by faults near Jumping Moose Lake. Most of the rocks are quartz-feldspar porphyry schists that are light grey on fresh surfaces and weather light pink or white. No primary volcanic textures are preserved. In a few outcrops, where the rocks are less deformed, it is possible to recognize volcaniclastic rocks (Photo 7.3) ranging from tuff to lapillistone. Fragments are rounded or subrounded, vesicular and amygdaloidal. Matrix and fragments are composed of the same material and may have been deposited by a debris flow mechanism. Due to the lack of top indicators in this area, it is difficult to determine the relationship between this unit and the adjacent mafic metavolcanic flow. The unit is probably calc-alkalic dacitic to andesitic in composition.

A large band of felsic to intermediate metavolcanic rocks is found in southern Kemp Township. Near Marne Lake, these rocks are pyroclastic and volcaniclastic in origin. To the east, toward Grassy Lake, the character of the rocks change to quartz and/or feldspar phenocryst-bearing flows across a short distance and change laterally into massive and autoclastic breccia flows that comprise the bulk of the sequence.

Pyroclastic rocks are best observed on the Marne Lake shoreline. They are light grey on fresh surfaces and weather white. Thin tuffaceous beds are interbedded with metre-thick beds of lapilli tuff. All clasts are massive and contain few vesicles or amygdules. The quartz and/or feldspar porphyritic flows have a fine-grained massive matrix, a light grey or light green fresh surface and a white weathered surface. The subhedral phenocrysts make up 5 to 10% of the rock and are between 1 and 10 mm in size.

The massive and autoclastic breccia flows form 90% of the sequence and are best observed on a ridge, 2 km long, along Grassy Road (200 m west of the road). The massive flow has a light grey, greenish grey or light green fresh surface; a whitish weathered surface; and locally contains some quartz amygdules, feldspar phenocrysts and disseminated sulphide minerals. The autoclastic breccia flow (Photo 7.4) is light grey or greenish grey and weathers white. The breccia fragments are angular and vary a great deal in size (1 to 50 cm) and form, but are the same composition as the matrix. The breccia was probably formed as the flow was erupted due to the high viscosity of the lava or due to the high hydrostatic pressure caused by the water column. Locally, the flow contains quartz- or carbonate-filled amygdules. Both flows are hard and brittle and locally have chlorite and carbonate alteration. This sequence of felsic to intermediate metavolcanic rocks could be calc-alkalic andesitic to dacitic or even rhyolitic in composition.

The felsic to intermediate metavolcanic sequence found in northern Mond and Kemp townships may be part of the Halliday felsic dome (Mullen 1983), centred in Halliday and Sotham townships to the north. Massive, pillowed, autoclastic breccia and porphyritic flows are found in this sequence. The flows are massive and pillowed along Grassy River and Ferris Lake and have a dark green fresh surface that weathers to a brownish appearance. This part of the sequence is intermediate in composition and could be the southern edge of the Halliday felsic dome. The rest of the sequence, toward the north border of the townships, consists of massive flows, autoclastic breccia and/or porphyritic flows. These flows are green or light green and have light grey or white weathered surfaces. They contain numerous quartz- and/or carbonate-filled amygdules (up to 50% locally). Subhedral feldspar phenocrysts are also found in some areas and hyaloclastite can be observed in a few locations. This sequence is probably dacitic to rhyolitic in composition, becoming andesitic near Grassy River.

Photo 7.3. Felsic to intermediate lapilli tuff near Jumping Moose Lake.

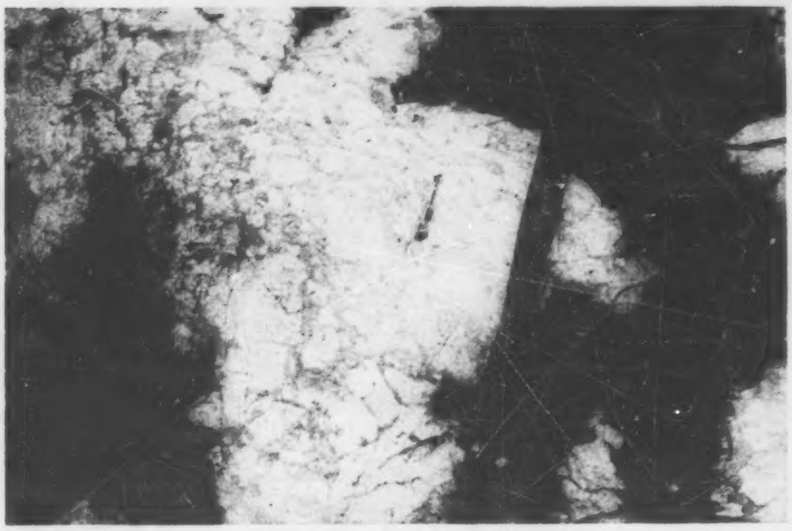

Photo 7.4. Felsic to intermediate autoclastic breccia near Grassy Road.

CHEMICAL METASEDIMENTARY ROCKS

Iron formation was intersected in diamond-drill core near Jumping Moose Lake ((Mullen 1983; Pyke 1982). It is associated with mafic and ultramafic metavolcanic rocks of the area and likely represents interflow metasedimentary rocks. These rocks (*see* Figure 7.1) have not been encountered in outcrop, but may be responsible for a total field magnetic anomaly on airborne geophysical magnetic maps (Ontario Geological Survey 1996).

METAMORPHOSED MAFIC TO ULTRAMAFIC INTRUSIVE ROCKS

Mafic to ultramafic intrusive rocks are common in Burrows and Kemp townships (*see* Figure 7.1). They appear as sill-like bodies intruding the Keewatin-age metavolcanic rocks. They are green, dark green or black on fresh surface and weather black or a mottled black and white. They vary in composition from dunite, peridotite, pyroxenite to gabbro. Gabbro is the most common type of rock in this category and makes up 90% of the intrusions. Usually, they are fresh and primary igneous textures, such as subophitic textures, are well preserved, except in the Jumping Moose Lake area, where the intrusions are sheared and the metamorphic grade is higher. Minor pyrite and leucoxene crystals are disseminated throughout the intrusions.

TIMISKAMING ASSEMBLAGE CLASTIC METASEDIMENTARY AND REWORKED METAVOLCANIC ROCKS

This sequence is located in southern Mond and southeastern Kemp townships (*see* Figure 7.1). The sequence lies unconformably over Keewatin-age metavolcanic rocks (Johns 1999), but this relationship was not observed in the map area. Clastic metasedimentary rocks range from siltstone, wacke, sandstone, and polymictic conglomerate, whereas the reworked metavolcanic rocks range from primary pyroclastic to volcaniclastic-epiclastic rocks.

Metasedimentary rocks compose 85% of the sequence, are immature and poorly sorted. Conglomerate clasts have a large range in composition: chert (Photo 7.5), jasper, mafic metavolcanic rocks, felsic metavolcanic rocks and volcaniclastic rocks. The fragments range in size from 1 to 10 cm and are rounded to subangular. The matrix is composed of euhedral or subhedral crystals of quartz, amphibole and feldspar. Fresh surfaces are grey, dark grey or black, and weathered surfaces are white or light grey. Siltstone, wacke and sandstone have the same composition and colour as the conglomerate, therefore, they are differentiated by grain size. This sequence was deposited rapidly, possibly by debris flow and turbidite mechanisms.

Interbedded with the clastic metasedimentary and volcaniclastic-epiclastic rocks are fine beds of tuff and lapilli tuff. A 20 cm thick bed is composed of accretionary lapilli, implying that its source eruption event happened in moist subaerial conditions. The thin nature of the beds could indicate either a distal source or a minor event. Colour and mineral composition of this sequence indicates a calc-alkalic andesitic composition.

Photo 7.5. Rounded chert clast in Timiskaming assemblage conglomerate.

GRANITIC INTRUSIVE ROCKS

Northwestern Burrows Township is underlain by a granitic batholith (*see* Figure 7.1) that intrudes the metavolcanic rocks. Textures vary from hypidiomorphic equigranular to foliated near contacts and faults. Grain size of the quartz, potassium feldspar and plagioclase increases from fine- to coarse-grained away from contacts and toward the interior of the intrusion. Compositionally, the batholith is granitic, quartz-syenitic or quartz-monzonitic and contains biotite as the main mafic mineral. It is possible that this batholith comprises several plutons or magmatic pulses, explaining the compositional variation and the large extent of the batholith, which is also found in several other townships to the north, west and south of the map area.

HURONIAN SUPERGROUP SEDIMENTARY ROCKS

This sequence covers a large area of the mapped townships (*see* Figure 7.1). It lies unconformably over the Archean rocks. It is composed of conglomerate, quartz arenite, wacke and siltstone; all are mature and well sorted.

Conglomerate is polymictic, matrix supported, pink or grey and weathers to a reddish tinge. No primary sedimentary structures were observed. Clasts are subrounded to rounded, vary in size from 5 to 70 cm and are composed of felsic metavolcanic rocks, mafic metavolcanic rocks, granite, diorite and gabbro. The matrix is sand size and is primarily composed of quartz.

Quartz arenite is red, grey or green, homogeneous, mature and well sorted. All mineral grains are rounded. The arenite may contain granite dropstones of 1 to 30 cm in diameter. The siltstone has a dark grey fresh colour, weathers white and has a vitreous lustre on the fresh surface.

Primary sedimentary structures were not observed in these rocks, except for bedding that is generally flat-lying with a dip between 0° and 10° and rare cross-bedding.

NIPISSING GABBRO AND MATACHEWAN DIABASE

One gabbro intrusion, interpreted to be similar to the Nipissing gabbros, occurs in the map area and is found in northern Mond Township (*see* Figure 7.1). The east-striking intrusion can be traced on airborne geophysical magnetic maps (Ontario Geological Survey 1996) into Kemp Township. This unit is layered and shows magmatic bedding. On an outcrop (50 m cross section on the Grassy River), it is possible to recognize 8 different layers of variable compositions, all related to the intrusion. Contacts between the layers are either gradational or sharp. Grain size and textures vary from layer to layer: some are fine grained, medium grained or even coarse grained. Sub-ophitic, granophyric and porphyritic textures were observed. Rock composition varies from gabbro to peridotite. Ilmenite and leucoxene are common oxide minerals found in the intrusion.

Matachewan diabase dikes are found throughout the map area. They are generally north-striking, magnetic, green-black on fresh surfaces and weather rusty-brown. They are massive, fine-grained, homogeneous and sometimes contain epidotized plagioclase phenocrysts. These dikes stand out as ridges against the surrounding topography.

METAMORPHISM AND ALTERATION

Rocks in the map area have undergone, in general, a low degree of metamorphism, apparently lower greenschist facies, except near Jumping Moose Lake and near the granitic batholith, where the metavolcanic rocks and mafic intrusions appear to have undergone lower amphibolite-facies metamorphism. Almost all of the Keewatin-age metavolcanic rocks have experienced low to moderate degrees of carbonatization, chloritization, silicification and sericitization. No prominent zones of pervasive alteration or intense alteration have been noted.

VOLCANOLOGY

Throughout the area, the Keewatin-age mafic metavolcanic rocks were deposited in a deep, subaqueous environment, as evidenced by the copious pillows and lack of abundant amygdules. The paucity of interflow metasediments in the mafic flows indicates rapid accumulation of lava. Based on their association with the mafic metavolcanic rocks, the felsic to intermediate metavolcanic rocks are presumed to be subaqueous.

The felsic to intermediate metavolcanic rocks range in depositional mode from massive flows with autoclastic breccia to ash flows and resedimented debris flows. Size and sorting cover the range from pyroclastic breccia to lapilli tuff to tuff. The sequence found in southern Kemp Township seems more proximal to vent facies in the west part of the sequence (Marne Lake area) and more distal toward the east, however, vent facies have not been positively identified.

STRUCTURAL GEOLOGY

In Burrows and Kemp townships, the Keewatin-age mafic metavolcanic rocks strike south-southeast, but change in orientation to northeast near Grassy Lake. The presence of top indicators suggests that the sequence youngs toward the west. In Mond Township, the units strike toward the north and young toward the east. The felsic Keewatin-age metavolcanic rocks in Burrows and Kemp townships strike east, while the rocks in Mond Township strike east and young to the south. Foliations present in the metavolcanic rocks and the mafic intrusions strike east-northeast.

The granitic intrusive rocks in Kemp Township are foliated at the margin of the batholith. The foliations have the same direction as the contacts, implying a possible forceful emplacement like a diapir intrusion.

The Timiskaming assemblage strikes southeast near Grassy Lake, but changes to a northeast strike toward the east. Supracrustal rocks in the area have been folded, but there is insufficient data to interpret possible fold axes.

The entire map area has been disrupted by northwest- and northeast-trending faults. Most of the faults appear to be sinistral, such as, for example, the Marne Lake fault where the lateral displacement is 3 to 4 km. The Marne Lake fault could be part of the Mattagami River fault. Deformation is restricted to these fault zones and their lateral extent is minimal. The faults resulted in shearing and foliation in the surrounding rocks, especially in the Jumping Moose Lake area. Faults in Mond Township, especially near Ferris Lake, affect the Huronian sedimentary rocks as well as the metavolcanic rocks.

The structure is more complex than what is described here, particularly in Burrows Township, but the lack of outcrop and reliable stratigraphic marker horizons made it difficult to interpret folding and faulting.

IMPLICATIONS FOR MINERAL EXPLORATION

Producing mines were never established in the map area, but mineral exploration has been occurring sporadically for at least the last 50 years. Exploration targets are aimed towards gold, base metals and platinum group elements (PGE).

Since the discovery, in 1949, of rich gold-bearing floats in the Jumping Moose Lake area (Tittley 1998), many claims have been staked and much exploration work has been completed (Assessment Files, Resident Geologist's Office, Kirkland Lake). The area is promising for gold due to the presence of granitic intrusions and major fault zones. Many gold deposits in the Abitibi greenstone belt are spatially associated with syenitic stocks, Timiskaming assemblage rocks and deformation zones (Robert 1997). The mafic metavolcanic rocks, south of Ferris Lake, are transected by at least two faults that should be regarded as having potential for gold.

The felsic to intermediate metavolcanic rocks in southern Kemp Township have been silicified and have potential for volcanogenic massive sulphide (VMS) deposits (Hanych 1996). The felsic metavolcanic rocks in northern Kemp Township should also be regarded as a possible target for VMS mineralization.

A low-grade nickel resource (300 000 tons of 0.9% Ni) has been outlined (Mullen 1983) in a mafic intrusion in Sothman Township with its continuation into Kemp Township. This resource is currently under investigation by Hucamp Mines Limited. The host rocks may be an ultramafic flow or intrusion.

An aeromagnetic anomaly, that is similar to an anomaly (Ontario Geological Survey 1996) associated with the nickel sulphide mineralization, is located southeast of Ferris Lake, but is covered by Huronian Supergroup sedimentary rocks. However, more exploration should be conducted in this area.

The layered Nipissing gabbro, north of Grassy River, should be investigated in more detail because the differentiation processes responsible for the formation of magmatic igneous layering can also serve to concentrate platinum group elements or other metals. Nipissing gabbro are known to have PGE potential (Jobin-Bevans, Keays and MacRae 1999) elsewhere in Ontario. At the time this report was written, assay results from the area were not yet available.

ACKNOWLEDGMENTS

We would like to thank the junior assistants L. Greenlaw, M. Hay and L. Radjnovich for their work during the field season. We would also like to thank J. Rudd for the preparation of numerous geophysical maps. J.A. Ayer, N.F. Trowell and B.R. Berger are thanked for the many insights they gave us during numerous discussions. Finally, thanks to all the support staff in the Ontario Geological Survey.

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8. Project Unit 00-043. Geology, Volcanology, Lithogeochemistry and Alteration Associated with Volcanogenic Base Metal Mineralization in the Big Four Lake Area, Shining Tree, Abitibi Greenstone Belt, Ontario

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INTRODUCTION

This study, supported under an Ontario Geological Survey–University of Ottawa Graduate Thesis Agreement, is part of a MSc thesis based at Ottawa University under the supervision of Dr. A.D. Fowler. The objective of the research is to describe and characterize the geology and volcanogenic, base metal mineralization within the Deloro assemblage, in the Shining Tree area. Massive sulphide mineralization is associated with highly altered intermediate to mafic metavolcanic flows overlying a felsic flow and/or dome complex.

The thesis area is located in the northwest part of Macmurchy Township (Figure 8.1). Bedrock mapping in the Shining Tree area was carried out by the Ontario Geological Survey during the 1970s (Carter 1987). As a result of recent exploration in the area, re-mapping at a scale of 1:50 000 was initiated in 1996 (Johns 1996, 1997, 1999a; Johns and Amelin 1999).

During the summer of 2000, detailed bedrock mapping at a scale of 1: 10 000 was undertaken using an exploration grid established by KRL Resources Corporation. During the mapping, 271 outcrops and diamond-drill core were documented. From these outcrops and from diamond-drill core samples, provided courtesy of KRL Resources Corporation, 40 samples were chosen for major oxide and selected trace element geochemical analysis. The samples include specimens taken from 4 KRL Resources Corporation diamond-drill holes where the base metal mineralization is well constrained.

The map area is located in the southern Abitibi greenstone belt. The study area is underlain by Keewatin-age rocks that can be subdivided into 2 assemblages: 1) the Pacaud assemblage, an ultramafic to mafic metavolcanic sequence (2741 +10/–8 Ma); and 2) the Deloro assemblage, a mafic to felsic metavolcanic sequence (2726 ± 1 Ma) (Johns and Amelin 1999), capped by chemical sediments. Both assemblages are intruded by Proterozoic-age Nipissing gabbro and Matachewan diabase dikes. Only the Deloro assemblage was studied during this project.

The data on the geological map (Figure 8.2) was compiled from Carter (1987), Johns (1999b), J. Watkins (Geologist, KRL Resources Corporation, personal communication, 1999) and from data collected during the summer of 2000.

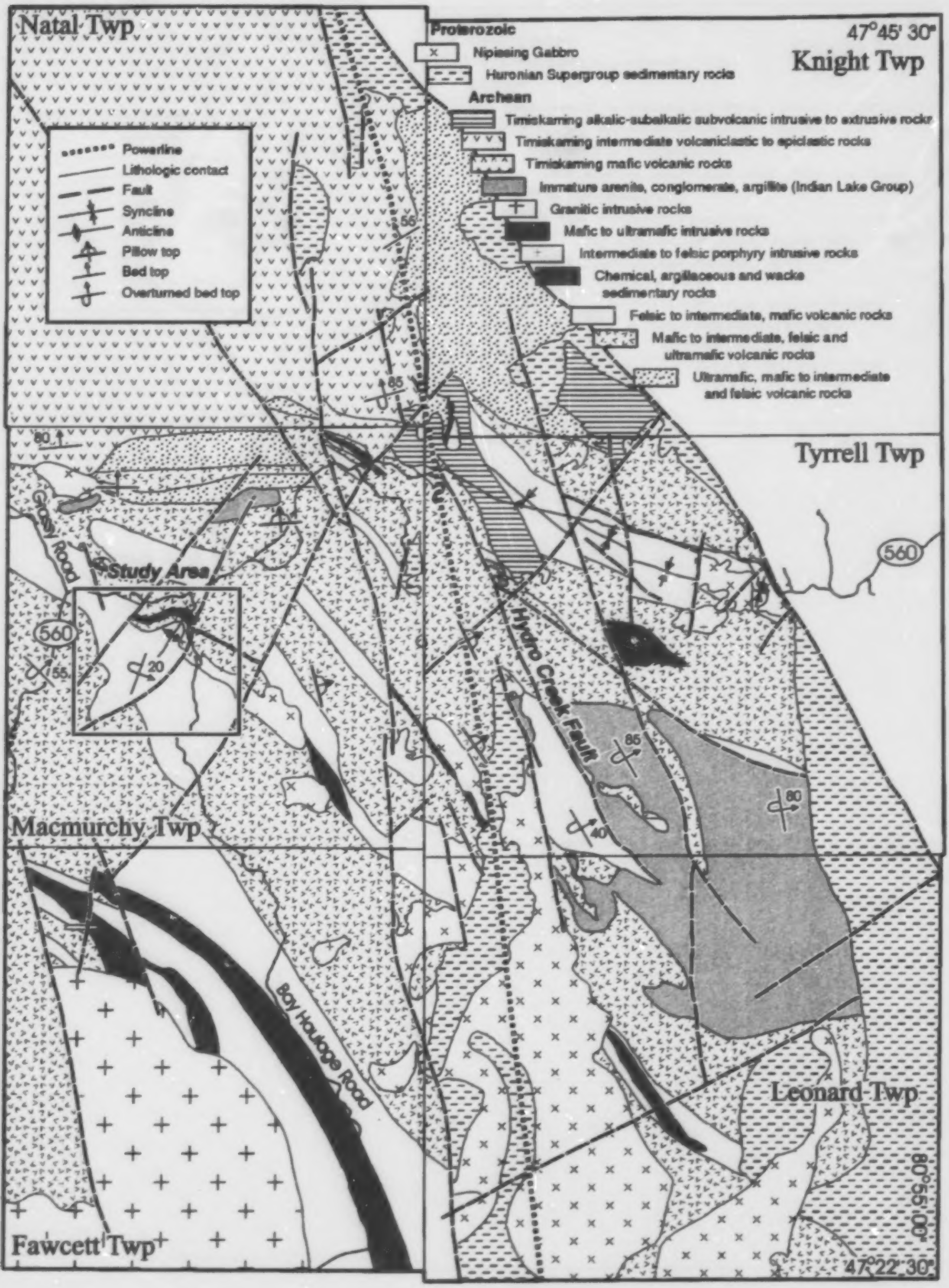
Natal Twp
Knight Twp
47°45' 30"
Proterozoic
Nipissing Gabbro
Huronian Supergroup sedimentary rocks
Archean
Timiskaming alkalic-subalkalic subvolcanic intrusive to extrusive rocks
Timiskaming intermediate volcaniclastic to epiclastic rocks
Timiskaming mafic volcanic rocks
Immature arenite, conglomerate, argillite (Indian Lake Group)
Granitic intrusive rocks
Mafic to ultramafic intrusive rocks
Intermediate to felsic porphyry intrusive rocks
Chemical, argillaceous and wacke sedimentary rocks
Felsic to intermediate, mafic volcanic rocks
Mafic to intermediate, felsic and ultramafic volcanic rocks
Ultramafic, mafic to intermediate and felsic volcanic rocks
Powerline
Lithologic contact
Fault
Syncline
Anticline
Pillow top
Bed top
Overturned bed top
Tyrrell Twp
Grassy Road
Study Area
560
55
20
56
65
80
85
40
Hydro Creek Fault
Macmurchy Twp
Bay Haulage Road
Leonard Twp
Fawcett Twp
80°55'00"
47°22'30"

Figure 8.1. Location map of the thesis area in the Shining Tree area. Figure *modified from* Johns and Amelin (1999).

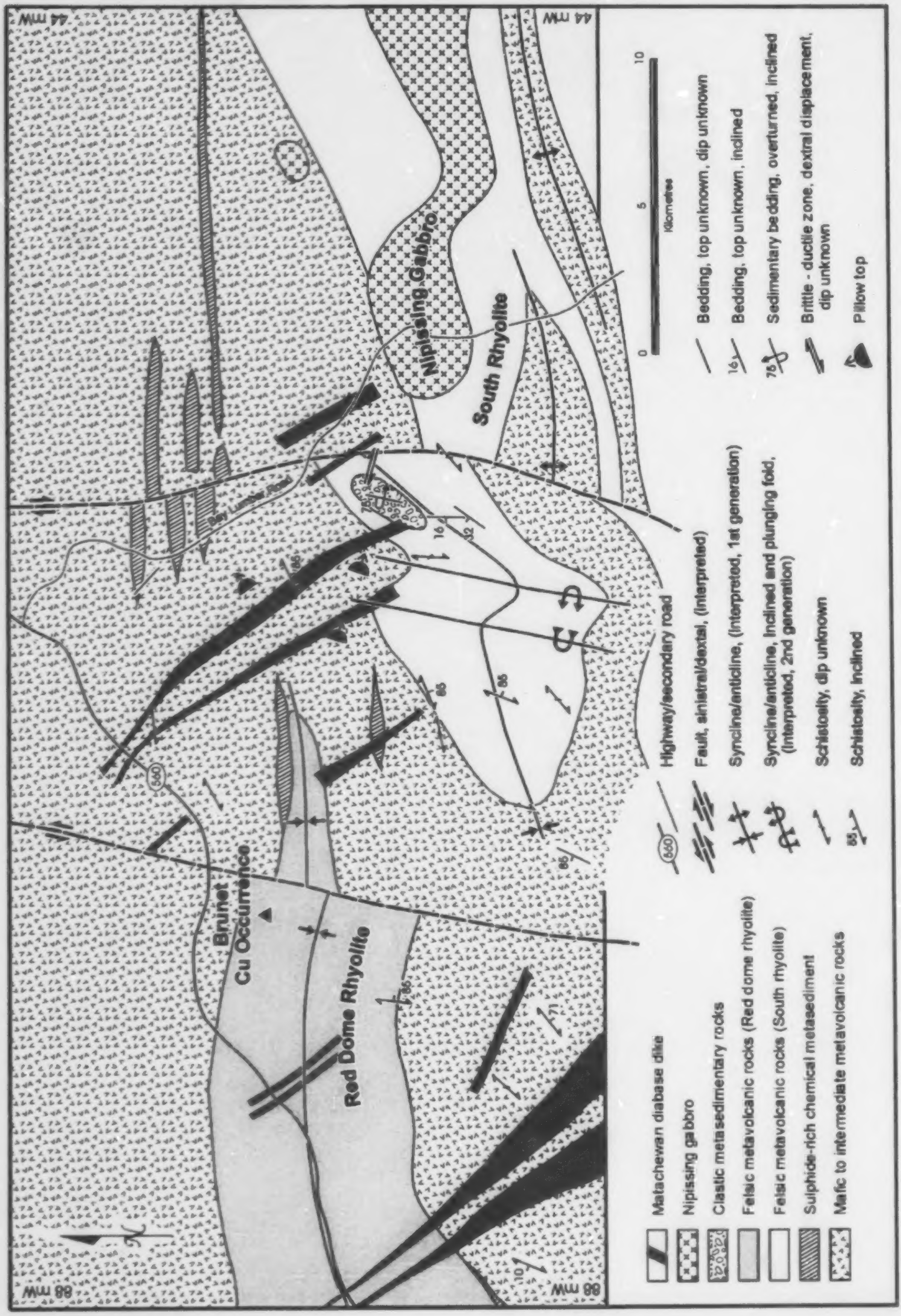
Nipissing Gabbro
South Rhyolite
Red Dome Rhyolite
Brunet Cu Occurrence
Bay Lumber Road
560
88 mW
44 mW
0
5
10
Kilometres
Matachewan diabase dike
Nipissing gabbro
Clastic metasedimentary rocks
Felsic metavolcanic rocks (Red dome rhyolite)
Felsic metavolcanic rocks (South rhyolite)
Sulphide-rich chemical metasediment
Mafic to intermediate metavolcanic rocks
Highway/secondary road
Fault, sinistral/dextral, (interpreted)
Syncline/anticline, (interpreted, 1st generation)
Syncline/anticline, inclined and plunging fold, (interpreted, 2nd generation)
Schistosity, dip unknown
Schistosity, inclined
Bedding, top unknown, dip unknown
Bedding, top unknown, inclined
Sedimentary bedding, overturned, inclined
Brittle - ductile zone, dextral displacement, dip unknown
Pillow top

Figure 8.2. Detailed geology map of the study area, Shining Tree, Ontario.

The geological structures illustrated in Figure 8.2 were interpreted from the relative position of lithologic units; from stratigraphic relationships; and from structural measurements. The area has been affected by 2 phases of deformation: a first phase in which fold axes are generally east trending; and a second phase in which the fold axes are north trending.

Following is a brief description of the units.

MATACHEWAN DIABASE DIKES

The majority of these north-striking dikes (*see* Figure 8.2) are fine-grained diabase and gabbro containing approximately 10 to 15% magnetite and millimetre-wide veins of epidote alteration. Some dikes contain epidotized plagioclase phenocrysts less than 1 cm in size. Secondary chlorite and calcite are also present in the matrix.

NIPISSING GABBRO

Outcrops of this unit (*see* Figure 8.2) are similar in appearance to the above, but are more coarse grained, being composed of gabbro containing approximately 60% pyroxene and 40% feldspar. The gabbro lacks the feldspar phenocrysts and prominent epidotization observed in the Matachewan diabase dikes.

DELORO ASSEMBLAGE

Clastic Metasedimentary Rocks

This unit (*see* Figure 8.2) is a conglomerate composed of volcanic material. Clasts range in size from sand to cobble size, and are generally subangular. Sedimentary structures such as flames and graded beds are preserved. Although there are mafic clasts present, most clasts have a pale appearance and are likely felsic in composition.

Chemical Metasedimentary Rocks

The chemical metasedimentary rocks (*see* Figure 8.2) comprise thinly laminated, brecciated red chert. They contain decimetre-thick zones having abundant submillimetre-size pyrite grains and, locally, millimetre-size grains of specular hematite.

Felsic Metavolcanic Rocks: Red Dome Rhyolite

This unit is massive, possibly containing some horizons of autoclastic breccia, and is interpreted to be a felsic dome (*see* Figure 8.2). Columnar joints were observed in parts of this unit. The rock is composed of millimetre-size, rounded phenocrysts of quartz and alkali feldspar within a fine-grained quartzo-feldspathic matrix. The rock has a pronounced red colour due to hematite alteration. Feldspar phenocrysts are less than a millimetre in size and are altered to sericite. Cores of some feldspar crystals are completely replaced by sericite. This unit also contains copper sulphide mineralization (Brunet copper occurrence, *see* Figure 8.2) consisting of a mineral assemblage of chalcopyrite-malachite-pyrite in quartz veins.

Felsic Metavolcanic Rocks: South Rhyolite

This unit (*see* Figure 8.2) is dominantly massive, but includes horizons of pyroclastic facies rocks (Johns and Amelin 1999). The rock is composed of a fine-grained matrix with phenocrysts of alkali feldspar and quartz. The quartz phenocrysts have been partially resorbed and the feldspar phenocrysts are variably altered to sericite. In a pyroclastic breccia exposed on the Bay Lumber road (*see* Figure 8.2), the matrix contains some arcuate structures which are interpreted to be perlitic fractures. Compared to the rest of the thesis area, the majority of the South rhyolite is deformed, as evidenced by a prominent penetrative foliation due to the alignment of sericite in the matrix.

MAFIC TO INTERMEDIATE METAVOLCANIC ROCKS

This unit is composed of both massive and pillowed mafic metavolcanic flows (*see* Figure 8.2). The rocks are fine grained and altered to chlorite. Millimetre-size patches of a fine-grained mineral, interpreted to be originally amphibole, are altered to chlorite. The presence of primary amphibole indicates that the flows may be intermediate in composition. Centimetre-size chlorite and calcite-filled amygdules are common. Parts of this unit are mineralized and contain minor pyrite and rare chalcopyrite in brecciated horizons.

LITHOGEOCHEMISTRY

Forty rock samples were submitted to the Geoscience Laboratories, Ontario Geoservices Centre, Sudbury, for analysis of major oxides, rare earth element (REE) and other trace elements. Selected chemical analyses for the Red Dome and South rhyolite units are presented in Table 8.1.

There are 2 general trends visible in the REE patterns (Figure 8.3). Deloro assemblage mafic to intermediate metavolcanic rocks are characterized by generally flat REE patterns and total REE abundances ranging from about 7 to 70 times chondrite. The felsic metavolcanic rocks of the Deloro assemblage commonly have light rare earth element (LREE) enrichment resulting in steeper REE patterns, that is, $(La/Lu)_{cn} \approx 10$ for the Red Dome rhyolite, and $(La/Lu)_{cn} \approx 25$ for the South rhyolite.

The flat patterns are characteristic of rocks that belong to tholeiitic suites, whereas the light rare earth element (LREE) enrichment of the Deloro assemblage felsic rocks is characteristic of calc-alkaline suites (Henderson 1984). Cation plots (Jensen 1976) for the same rocks confirm the above interpretation. The mafic to intermediate metavolcanic rocks of the Deloro assemblage generally fall within the limits of the fields of high-Fe tholeiitic basalt, andesite and dacite. In contrast, the Deloro assemblage felsic rocks are grouped within the domain of calc-alkaline rhyolite. Ayer et al. (1999) have noted that the Deloro assemblage in the Timmins area consists of calc-alkalic mafic and felsic metavolcanic rocks. It remains an open question as to why the Deloro assemblage in the Shining Tree area has characteristics of both the tholeiitic and calc-alkaline suites.

In terms of the rhyolite trace element geochemical classification of Lesher, Goodwin and Gorton (1986), the Red Dome rhyolite and South rhyolite best conform to the type FI group with some FII characteristics. In general, the REE patterns for these rocks are steep (*see* Figure 8.3), have moderate negative to very slight positive Eu anomalies. Zr/Y ratios are between approximately 3 and 22, and have low abundances of high-field-strength elements (e.g., Y ≈ 5 to 34 ppm, Zr ≈ 73 to 207 ppm, and Hf ≈ 3 to 7 ppm). The Sr abundances range from approximately 15 to 243 ppm (*see* Table 8.1).

Table 8.1. Selected whole-rock geochemical analyses of South rhyolite and Red Dome rhyolite.

	South Rhyolite Suite						Red Dome Rhyolite Suite					
Sample No.:	**6005**	**6034**	**6036**	**6042**	**6048**	**6055**	**6018**	**6013**	**6019**	**6020**	**6021**	**6043**
SiO_2 (wt%)	71.22	66.91	77.72	69.20	52.16	71.02	76.49	75.61	75.25	75.81	75.52	75.90
TiO_2	0.37	0.30	0.15	0.38	1.26	0.31	0.05	0.09	0.06	0.11	0.05	0.06
Al_2O_3	16.12	20.14	13.26	16.71	17.96	16.59	12.54	14.30	12.85	13.77	14.40	13.49
Fe_2O_3	2.50	2.07	2.36	3.38	14.01	1.82	1.45	1.55	1.40	1.06	0.86	1.19
MnO	0.07	0.03	0.05	0.07	0.14	0.04	0.03	0.03	0.04	0.03	0.00	0.00
MgO	1.29	1.13	0.73	1.37	7.09	0.73	0.47	0.59	0.77	0.49	0.29	0.39
CaO	2.14	1.88	2.25	3.49	3.81	2.62	1.44	1.13	1.71	1.19	0.50	0.04
Na_2O	4.73	4.21	0.63	2.98	2.34	3.91	1.05	2.24	3.30	3.65	0.65	0.61
K_2O	1.48	3.27	2.82	2.33	0.99	2.89	6.46	4.44	4.59	3.87	7.72	8.31
P_2O_5	0.08	0.07	0.02	0.07	0.24	0.06	0.01	0.02	0.02	0.02	0.01	0.01
Rb (ppm)	42.41	58.34	55.08	50.31	31.04	87.26	114.91	100.87	83.65	94.51	126.84	134.23
Ba	253.27	484.57	395.33	359.43	165.03	486.11	664.93	376.66	654.23	503.26	466.80	754.88
Sr	181.64	195.04	72.28	123.31	105.06	243.35	18.16	16.38	53.80	47.45	15.34	17.69
Sc	5.00	4.00	6.00	5.00	18.00	4.00	1.00	2.00	2.00	3.00	1.00	1.00
Cr	56.24	58.50	53.20	55.26	76.18	22.67	53.83	50.43	56.12	51.66	50.94	63.88
La	13.89	11.82	91.14	12.55	14.65	10.72	17.21	26.78	20.54	23.44	30.22	20.03
Ce	27.26	23.84	182.73	25.05	34.78	22.15	36.62	54.10	43.96	49.01	42.11	39.33
Nd	12.17	11.19	76.19	11.31	19.91	10.51	17.16	24.52	21.30	22.56	10.31	16.42
Sm	2.07	1.97	10.98	2.08	3.94	1.86	3.64	5.14	4.81	4.71	1.33	3.17
Eu	0.64	0.51	1.58	0.59	1.09	0.57	0.52	0.86	0.61	0.72	0.38	0.64
Tb	0.21	0.21	1.08	0.20	0.52	0.17	0.60	0.78	0.80	0.72	0.25	0.39
Yb	0.57	0.60	3.94	0.59	1.78	0.37	2.39	3.07	3.04	2.77	1.54	1.60
Lu	0.09	0.10	0.65	0.09	0.26	0.06	0.38	0.46	0.48	0.43	0.26	0.26
Y	6.59	6.45	37.08	6.37	18.12	4.58	25.26	31.59	34.06	29.34	12.23	14.45
Zr	107.92	119.39	207.08	110.05	151.57	100.52	73.39	105.87	78.75	103.21	80.67	86.38
Th	1.44	1.39	7.77	1.54	1.70	1.06	7.04	8.03	6.75	7.51	8.21	7.58
U	0.38	0.45	0.61	0.28	0.43	0.30	2.01	2.42	1.92	2.37	2.06	1.54
Hf	2.99	3.49	6.63	3.34	4.07	2.91	3.04	3.98	3.32	3.92	3.55	3.53
Ta			0.98		0.59		1.24	1.51	1.53	1.38	1.45	1.46
La/La_{CHUR}	36.75	31.27	241.11	33.20	38.76	28.36	45.53	70.85	54.34	62.01	79.95	52.99
Yb/Yb_{CHUR}	2.29	2.41	15.82	2.37	7.15	1.49	9.60	12.33	12.21	11.12	6.18	6.43
$(La/Yb)_{(n/1.2)}$	13.38	10.81	12.70	11.68	4.52	15.90	3.95	4.79	3.71	4.65	10.77	6.87
Eu*	10.00	9.50	52.50	9.75	20.71	8.75	21.43	28.57	28.57	27.14	8.00	17.08
Eu/Eu*	0.0640	0.0537	0.0301	0.0605	0.0526	0.0651	0.0243	0.0301	0.0214	0.0265	0.0475	0.0375
Zr/Y	16.38	18.51	5.58	17.28	8.36	21.95	2.91	3.35	2.31	3.52	6.60	5.98

Notes: Major elements by XRF recalculated to 100% volatile-free; total iron as Fe_2O_3; Rb, Sr Y, Zr by XRF; remaining trace elements by INAA. *Calculated by linear interpolation between chondrite-normalized Sm and Tb on Figure 8.3. La_{CHUR} and Yb_{CHUR} values come from Leedy chondrite (Masuda *et al.* 1973).

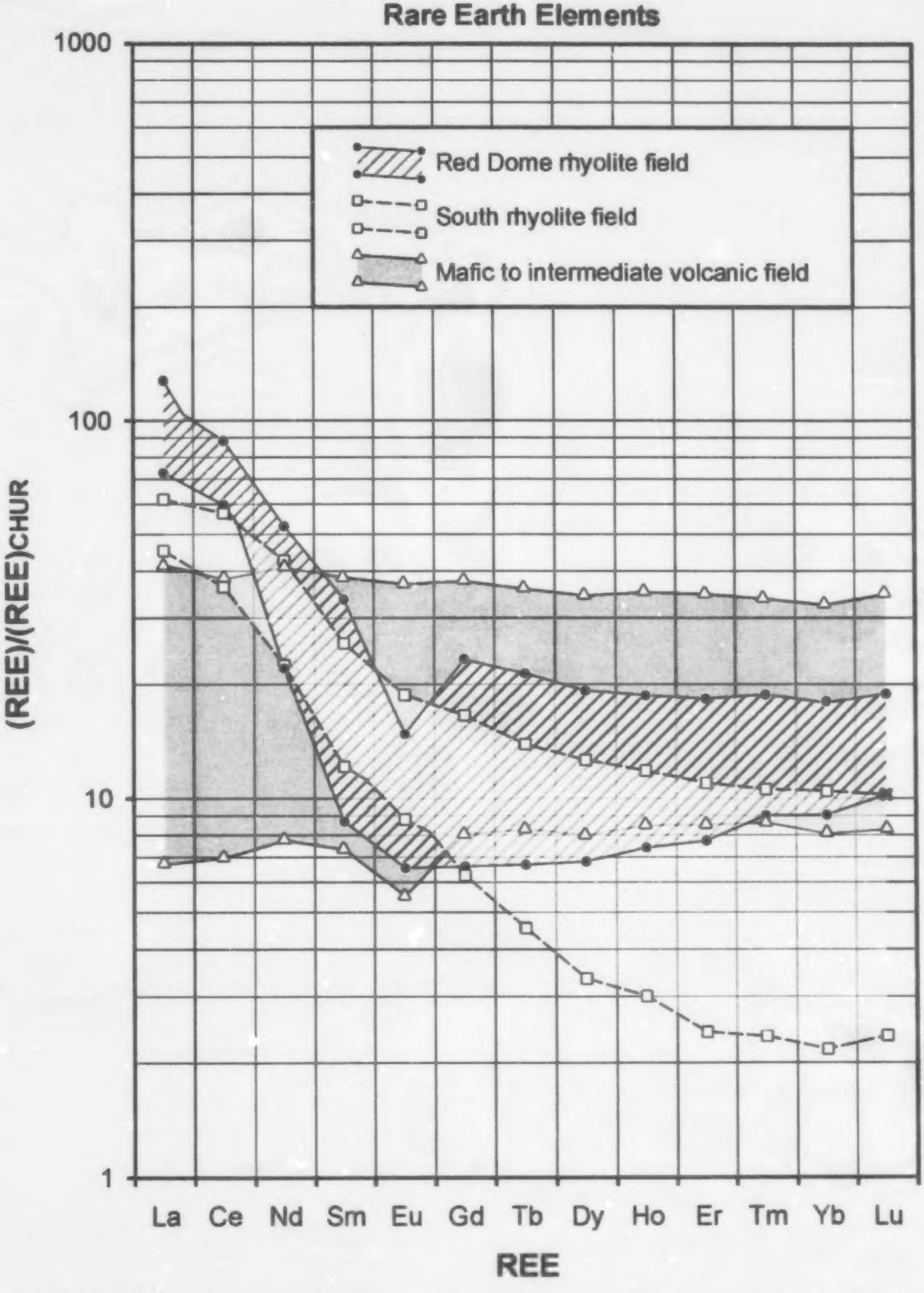

Figure 8.3. REE patterns of the Deloro assemblage rocks. Chondrite abundances used for normalization *from* Sun and McDonough (1989). Symbols: □, South rhyolite; •, Red Dome rhyolite; Δ, mafic to intermediate metavolcanic rocks.

ALTERATION

The following petrographic observations of alteration are from an outcrop on Highway 560, near the Brunet (*see* Figure 8.2) copper occurrence. The host rock is the Red Dome rhyolite, part of the Deloro assemblage. Alteration visible on outcrop is chiefly composed of an intense hematization and sericitization.

Thin section analyses show that the rock contains thin veins (≈250 µm) of either feldspar or Fe-Ti oxide minerals. These veins are crosscut by later, thin, sericite, carbonate-bearing veins. Quartz veins transect the sericite veins. In addition, the majority of the alkali feldspar phenocrysts are altered to sericite.

Alteration of the mafic metavolcanic units of the Deloro assemblage is characterized by a pervasive chlorite-carbonate mineral assemblage found throughout the matrix and also in the amygdules. Chlorite-calcite alteration, as well as epidote alteration, is evident in the Nipissing gabbro and Matachewan diabase dikes of the area.

Continued research involves detailed petrography in order to characterize the igneous and metamorphic textures, alteration minerals and, where possible, the primary mineralogy of the rocks. The research will also detail the ore mineralogy and associate the mineralization zones with the alteration pattern. The mineralogy will be further compared with the results of the geochemical analyses to better classify the rocks and their alteration.

ACKNOWLEDGMENTS

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9. Project Unit 97-024. Variation in Styles of Gold Mineralization along the Porcupine–Destor Deformation Zone in Ontario: An Exploration Guide

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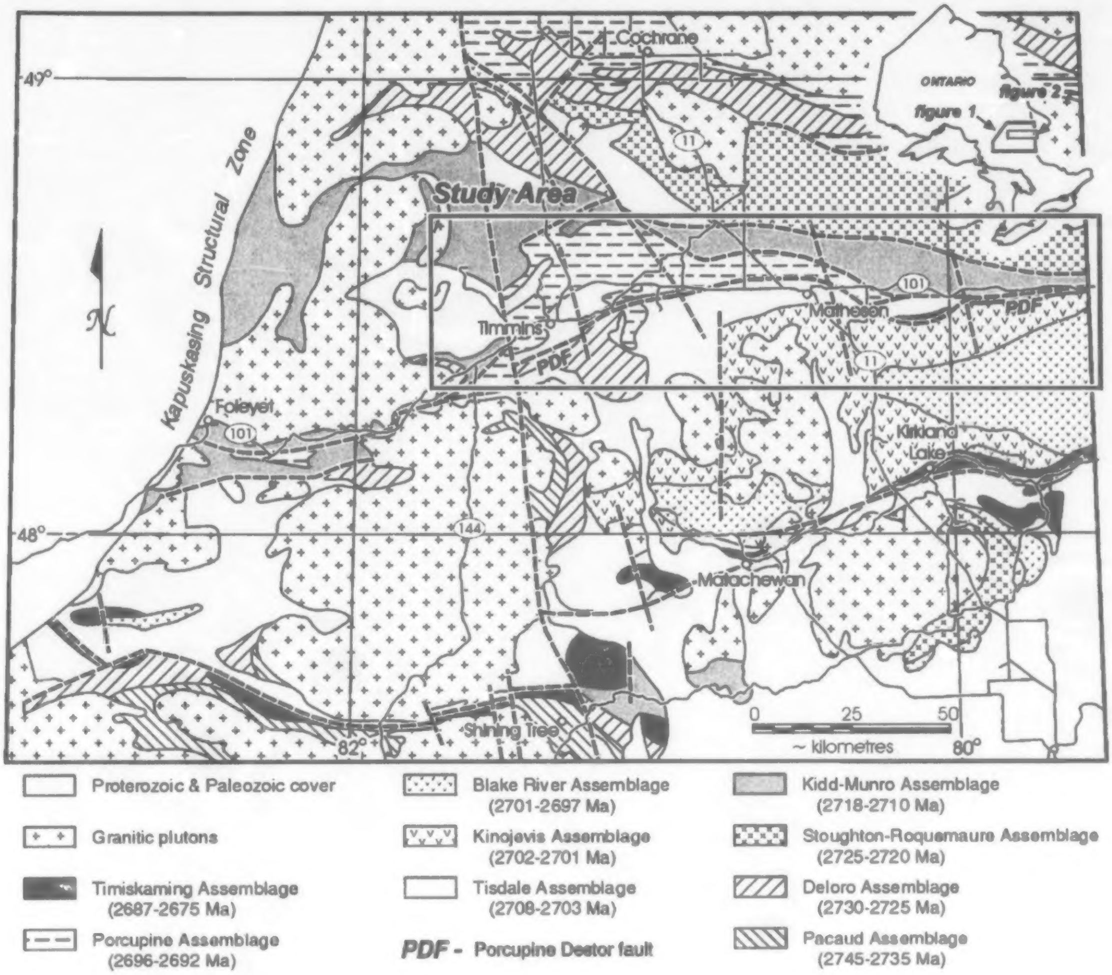
INTRODUCTION

The spatial association of gold deposits with the Porcupine–Destor deformation zone (PDDZ), a regional largely strike-slip structure extending for over 450 km in the Abitibi greenstone belt of Canada, is long recognized (Figure 9.1). The world-class Timmins mining camp in northern Ontario is the most notable cluster of gold deposits along this structure. Numerous studies describe the geology and mineralization in the Timmins area (Brisbin 1997; Melnik-Proud 1992; Wood et al. 1986; Pyke 1982). In the last 20 years, several new gold deposits, discovered between Timmins and the Quebec border, are also recognized to be spatially associated with the PDDZ. Although these deposits display gross similarity to those in Timmins, there are significant differences in structural setting and styles of mineralization. Recent mapping and compilation by the Ontario Geological Survey (OGS) demonstrates that the variations in styles of gold mineralization occur systematically along the PDDZ (Berger 1994, 1996, 1997, 1999, 2000; Berger and Amelin 1999; Ayer and Trowell 1998; Ayer, Berger and Trowell 1999). This paper will examine the variations in mineralization style and geology; will demonstrate that different mineralization styles occur within discrete segments along the PDDZ; and that each segment is bounded, to a first-order approximation, by north-northwest-striking faults that transect the PDDZ. These faults have vertical components of movement, therefore, they are inferred to expose different crustal levels along the PDDZ and the variability amongst all gold deposits can be reconciled with a crustal continuum model of gold mineralization (Groves et al. 1992; Colvine et al. 1988). Gold deposits also display alteration minerals, vein styles and rock type associations that vary with proximity to felsic intrusive centres along the PDDZ and models proposed by Robert (1998) and Robert and Poulsen (1997) are applicable.

Five segments, each bounded by north-northwest-striking faults that transect the PDDZ are recognized: Timmins, Pamour, Nighthawk–Matheson, Hislop–Michaud and Harker–Holloway (Figure 9.2). Table 9.1 summarizes the variations in mineralization style within each segment and it is emphasized that all features may not be present at each deposit within a segment.

REGIONAL SETTING

The area between Timmins and Quebec (approximately 140 km) is underlain by Neoarchean and Proterozoic rocks covered by extensive Quaternary glacio-fluvial and lacustrine sediments. The Neoarchean supracrustal rocks are divided into lithotectonic assemblages proposed by Jackson and Fyon (1991) and modified by Ayer et al (1999) (*see* Figure 9.2). The Deloro, Tisdale–Bowman, Kidd–Munro, and Kinojevis assemblages are composed predominantly of metavolcanic rocks and are unconformably


49°
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Cochrane
11
ONTARIO
figure 2
figure 1
Kapuskasing Structural Zone
Study Area
N
Timmins
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101
Matheson
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11
Foleyet
101
Kirkland Lake
144
Matachewan
Shining Tree
82°
80°
0 25 50
~ kilometres
Proterozoic & Paleozoic cover
Granitic plutons
Timiskaming Assemblage (2687-2675 Ma)
Porcupine Assemblage (2696-2692 Ma)
Blake River Assemblage (2701-2697 Ma)
Kinojevis Assemblage (2702-2701 Ma)
Tisdale Assemblage (2708-2703 Ma)
PDF - Porcupine Destor fault
Kidd-Munro Assemblage (2718-2710 Ma)
Stoughton-Roquemaure Assemblage (2725-2720 Ma)
Deloro Assemblage (2730-2725 Ma)
Pacaud Assemblage (2745-2735 Ma)

Figure 9.1. Location map for the study area.

overlain by turbiditic metasedimentary rocks of the Porcupine assemblage. These assemblages were deformed prior to deposition of the alluvial–fluvial metasedimentary and alkalic metavolcanic rocks of the Timiskaming assemblage. Archean calc-alkaline and alkaline plutonic rocks are intruded along and near the PDDZ. Proterozoic quartz diabase and olivine diabase dikes intruded all rock types in the area.

The PDDZ is poorly exposed, consequently, its location and nature is derived largely from geophysics, diamond drill hole data and underground workings in the study area. It is a broadly east-striking structure composed of discrete brittle–ductile faults and anastomosing high-strain zones separating less deformed rocks. The PDDZ pinches, swells and bifurcates from less than 150 m to over 5 km wide and separates widely divergent rock types. There is general agreement that late south-side-up movement occurred on the fault zone (Pyke 1982; Brisbin 1997; Luinstra and Benn 2000), but there is conflicting evidence for dextral (Piroshco and Kettles 1991; Heather et al. 1995) versus sinistral (Brisbin 1997) lateral displacement. A strain regime dominated by flattening is inferred for PDDZ in the study area (Jackson and Fyon 1991; Luinstra and Benn 2000).

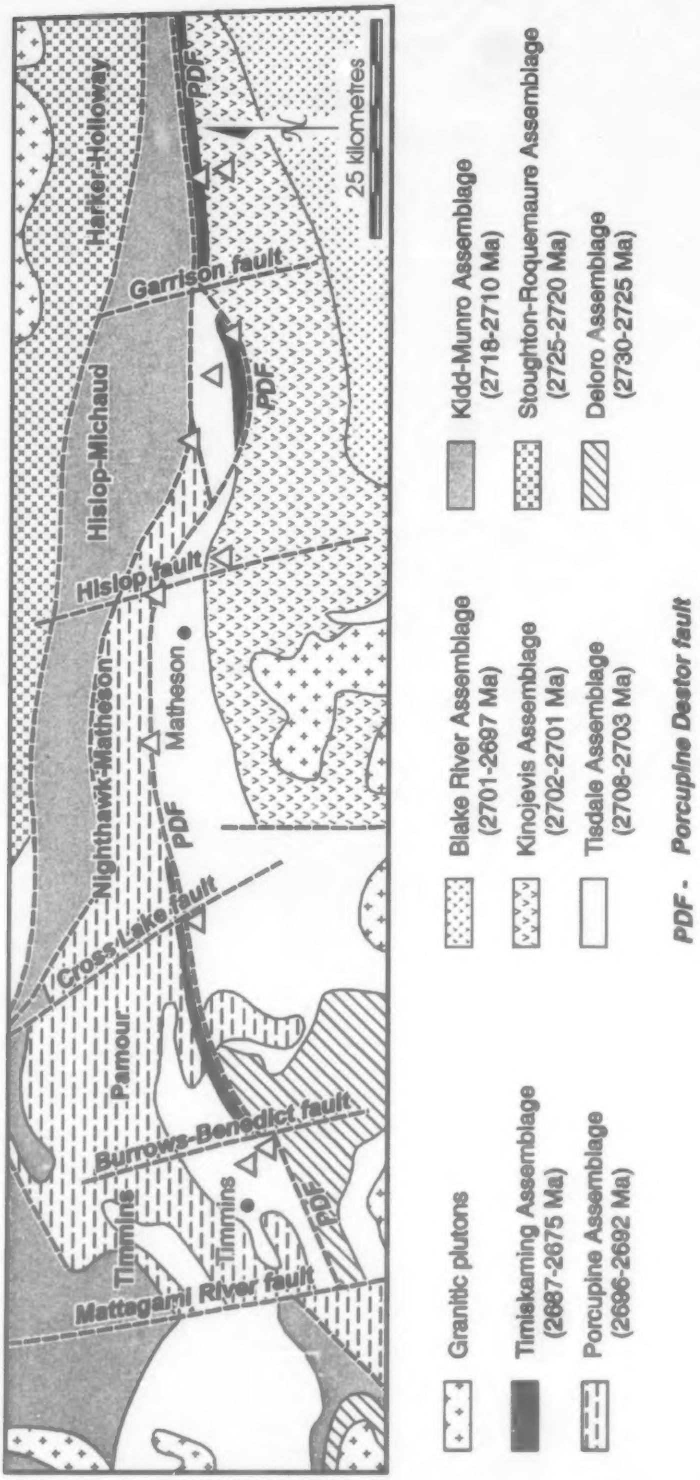
Harker-Holloway
Hislop-Michaud
Nighthawk-Matheson
Pamour
Timmins
Timmins
Matheson
Garrison fault
Hislop fault
Cross Lake fault
Burrows-Benedict fault
Mattagami River fault
PDF
PDF
PDF
PDF
N
25 kilometres
Granitic plutons
Timiskaming Assemblage (2687-2675 Ma)
Porcupine Assemblage (2696-2692 Ma)
Blake River Assemblage (2701-2697 Ma)
Kinojevis Assemblage (2702-2701 Ma)
Tisdale Assemblage (2708-2703 Ma)
Kidd-Munro Assemblage (2718-2710 Ma)
Stoughton-Roquemaure Assemblage (2725-2720 Ma)
Deloro Assemblage (2730-2725 Ma)
PDF - Porcupine Destor fault

Figure 9.2. General geology of the study area.

Table 9.1. Variation in styles of gold mineralization along the Porcupine–Destor deformation zone.

Segment	Length (approx.)	Gold Style	Structural Regime	Main Hosts	Main Alteration	Relation to PDDZ	PDDZ Character	Mineralization Age	Representative Deposit
Timmins	19 km	Stockwork qtz veins + py in wall rock,	Brittle to brittle–ductile	**QUARTZ-FELDSPAR PORPHYRY**, mafic metavolcanic rocks	alb + sil + ser + Fe-carb	North of PDDZ in splay faults	dips 60-80°N	Syn- to post-2673 Ma albitite	Hollinger–McIntyre
Pamour	27 km	Qtz ± carb veins	Brittle–ductile transition	**TIMISKAMING METASEDIMENTARY ROCKS**, mafic metavolcanic rocks	sil + ser	North of PDDZ at unconformity	steep	Post-2679 Ma Three Nations	Pamour
Nighthawk–Matheson	37 km	Disseminated py, qtz-carb stockwork	More ductile than brittle	ultramafic schist, feldspar porphyry, **ALBITITE**, metasedimentary rocks	sil + carb + ser	Along PDDZ	dips 45-65°S	Post-2682 Ma albitite	Taylor and Glimmer deposits
Hislop–Michaud	27 km	Disseminated sulphides, minor quartz-carbonate veins	Mainly ductile with brittle overprint	**ALKALIC PLUTONS**, mafic metavolcanic rocks, Timiskaming Metasedimentary Rocks	hem + alb + ser	NW faults, splays and secondary faults	near vertical	Pre-2678 Ma and post-2678 Ma alkalic intrusions	Pangea, Ludgate Lake
Harker–Holloway	29 km	Disseminated py, qtz-carb stockwork	More ductile than brittle	**MAFIC METAVOLCANIC ROCKS**, syenite, albitite	alb + sil + ser	Splay fault south of PDDZ and within PDDZ	75-85°S	Pre- and post-2671 Ma alkalic dikes	Holloway, Holt–Mcdermott

Abbreviations: alb, albitization; Fe-carb, iron carbonatization; hem, hematization; PDDZ, Porcupine–Destor deformation zone; py, pyrite; qtz-carb, quartz and carbonate; ser, sericitization; sil, silicification.

Ultramafic and mafic metavolcanic rocks occur along the entire length of the PDDZ. Timiskaming metasedimentary rocks are common, but may be locally absent as, for example, in much of the Nighthawk–Matheson segment (*see* Figure 9.2). Calc-alkalic quartz-feldspar porphyry intrusions are predominant north of the PDDZ in the Timmins segment and decrease in abundance eastward. Alkalic hornblendite, monzonite, syenite and quartz syenite intrusions are predominant north of the PDDZ in the Hislop–Michaud segment and decrease in abundance to the east and west. Pink to white, holocrystalline albitite is a minor rock type that occurs in all segments and provides an important unifying link in many of the gold deposits all along the PDDZ.

Several proposed tectonic models for the evolution of the southern Abitibi greenstone belt indicate that the PDDZ is a crustal-scale structure that developed in response to island-arc collision and subsequent rifting (Hodgson and Hamilton 1989; Corfu 1993; Mueller et al. 1996). Gold associated with the PDDZ is generally late and episodic with mineralization predating and postdating at least one regional deformational event (Brisbin 1997; Robert 1998; Luinstra and Benn 2000).

TIMMINS SEGMENT

The Timmins segment lies between the Mattagami River and Burrows–Benedict faults (approximately 20 km long, *see* Figure 9.2). The PDDZ is east-northeast striking, moderately to steeply north dipping and is approximately 150 m wide in the Timmins segment (Pyke 1982). It separates calc-alkaline metavolcanic rocks of the Deloro assemblage (ca. 2725 Ma) from komatiitic and tholeiitic metavolcanic rocks of the Tisdale assemblage (ca. 2706 Ma). South-side-up and sinistral displacement is inferred from the stratigraphy and structure, however, absolute magnitudes of movement remain unknown (Brisbin 1997; Pyke 1982). All the gold deposits in the Timmins segment occur north of the PDDZ on subparallel structures such as the Dome and Hollinger faults. Gold deposits in the Timmins segment are classified as intrusion-centred quartz vein arrays (Robert and Poulsen 1997) emplaced at a high (epizonal) crustal level (Mason, Brisbin and Aitken 1988; Brisbin 1997).

The major gold deposits within this block include the Hollinger–McIntyre and Dome mines, but a number of significant deposits including the Preston, Coniaurum and Paymaster also occur in this segment. A variety of rocks are host to gold mineralization, however, all major deposits occur near epizonal calc-alkaline quartz-feldspar porphyry intrusions that are approximately 2690 Ma (cf. Corfu 1993; Brisbin 1997). Quartz-carbonate vein arrays, commonly with disseminated sulphide haloes, formed in a dominantly brittle structural regime and comprise the bulk of the ore with gold occurring in pyrite or in the free state (Brisbin 1997; Robert and Poulsen 1997). Pyrite is the dominant sulphide mineral with pyrrhotite, chalcopyrite and sphalerite locally abundant. Hydrothermal alteration in the Timmins segment includes widespread calcite-chlorite with an inner zone of ankerite and sericite (Robert and Poulsen 1997; Brisbin 1997). Sodic alteration manifested as albitite dikes (ca. 2673 Ma) and pervasive albitization is a locus for subsequent brittle fracturing, veining and gold mineralization (Melnik-Proud 1992; Brisbin 1997).

PAMOUR SEGMENT

The Pamour segment lies between the Burrows–Benedict and Cross Lake faults (approximately 27 km long, *see* Figure 9.2). Numerous north-northwest-striking faults occur throughout this segment, such that future subdivision is possible. Schistose ultramafic rocks, that are well constrained by outcrop, geophysical, and diamond, sonic and reverse circulation drill hole data, mark the location of the PDDZ. However, the PDDZ is not well understood, as almost all studies are related to gold mineralization that occurs north of the fault zone or on the Nighthawk splay fault. The PDDZ is easterly striking, steeply

F2

north dipping to vertical and approximately 200 m wide, but vertical and lateral displacements are unknown. The structure separates the Deloro from the Tisdale–Bowman assemblages in the west and tholeiitic and calc-alkaline metavolcanic rocks of the Tisdale–Bowman assemblage from clastic metasedimentary rocks of the Porcupine assemblage (ca. 2695 Ma) in the east.

The major gold deposit in this segment is the Pamour Mine, but also included are the Hallnor and Hoyle deposits, and gold occurrences east of the Kidd Creek metallurgical complex. Timiskaming metasedimentary and mafic metavolcanic rocks are the main hosts to gold mineralization. Large calc-alkaline epizonal intrusions are absent although narrow discontinuous quartz-feldspar porphyry dikes occur throughout the segment. Gold deposits in the Pamour segment are sediment-hosted quartz veins and stockworks (Robert and Poulsen 1997) characterized by brittle–ductile laminated quartz-carbonate veins, sheeted quartz veinlets and disseminated sulphide mineralization that comprise the bulk of the ore with gold occurring in sulphides and in the free state. Pyrite is the dominant sulphide mineral with pyrrhotite, sphalerite and arsenopyrite common. Arsenopyrite is common and increases in abundance from west to east in the segment. Hydrothermal alteration is characterized by orebody zonation with a distal calcite-chlorite zone and a proximal sericite-ankerite-sulphide mineral zone. In general, the distal calcite-chlorite zone is not as widespread as in the Timmins segment. Albitite dikes occur throughout the Pamour segment as discontinuous, narrow lenticular dikes. They are broadly synchronous with early Timiskaming sedimentation as demonstrated by peperite textures developed in conglomerate and argillite adjacent to a dike in the Nighthawk Lake area.

NIGHTHAWK–MATHESON SEGMENT

The Nighthawk–Matheson segment lies between the Cross Lake and Hislop faults (approximately 37 km long) and includes the Aquarius, Stock, Taylor and Glimmer gold deposits plus other smaller deposits and occurrences (*see* Figure 9.2). The PDDZ is an easterly striking, moderately south-dipping (45 to 65°) ductile zone, up to 800 m wide, of schistose ultramafic and mafic rocks with tectonically interleaved metasedimentary rocks. Metavolcanic rocks of the Tisdale–Bowman assemblage are thrust north over turbidites of the Porcupine assemblage along the PDDZ. The Timiskaming metasedimentary rocks are cut off by the convergence of the PDDZ with the Nighthawk Lake fault; however, metasedimentary rocks structurally interleaved with ultramafic schist at the Shoot Zone are inferred to be Timiskaming (Shegelski 1989). Calc-alkaline feldspar porphyry and alkaline syenite and albitite intrusions occur locally within the PDDZ.

All gold deposits occur within the PDDZ or on the Nighthawk Lake fault to the south and generally conform to the host structure. The Aquarius deposit, however, forms an open anticlinal sheet centred on a syenite-albitite intrusion and contains northwest-striking high-grade zones parallel to the Cross Lake fault within a lower grade envelope. This suggests that the northwest faults may have had some local control on gold mineralization. Quartz-carbonate stockworks, sheeted quartz veins and disseminated pyrite zones developed in a predominantly ductile structural setting comprise the bulk of the ore and gold occurs in pyrite or as very fine free gold. Pyrite is the dominant sulphide mineral with chalcopyrite, molybdenite and iron oxide minerals subordinate. Rare occurrences of nickel arsenide minerals, including gersdorffite, in the mineralized wall rocks are unique to this segment and suggest higher temperatures for hydrothermal fluids than farther west. Ankerite and emerald green, chromium mica are the most common hydrothermal alteration minerals and generally increase in abundance as the ore zones are approached. Albite occurs in pervasive alteration zones and as albitite dikes and is characteristic of the most proximal alteration to ore. Significant amounts of apatite occur with albitite and syenite at the Aquarius, Taylor and Glimmer deposits and formed during an alteration process a process similar to fenitization (King and Kerrich 1987). High-grade gold occurs where the albitite intrusions and pervasive albitization are strongly pyritic (Worden, Cumming and Krstic 1995; Hoxha 1999). Sheeted albitite dikes at the Taylor deposit have an age of 2682 Ma (Worden, Cumming and Krstic 1995; *see* Table 9.1).

HISLOP–MICHAUD SEGMENT

The Hislop–Michaud segment lies between the Hislop fault and an unnamed north-northwest-striking fault in Garrison Township (approximately 27 km long, *see* Figure 9.2). A number of gold deposits occur within this segment; among the more important are the St. Andrew's Hislop pit, Ross Mine, Pangea, Ludgate Lake, SW zone and Buffonta deposits. Geology in the Hislop–Michaud segment is more complex and less well understood than in other segments. Stratigraphic correlation is complicated by the intrusion of several multi-phase alkaline plutons ranging in composition from hornblendite to granite. The location of the PDDZ, interpreted to follow the arcuate contact between Timiskaming metasedimentary rocks and ultramafic to mafic metavolcanic rocks tentatively correlated with the Tisdale–Bowman assemblage, is ambiguous as several east-northeast-striking, subvertical ductile shear zones and faults converge and crosscut the PDDZ. In the eastern part of the segment, the PDDZ bifurcates into the main branch and the Munro–Pipestone fault zone, another major gold-bearing crustal structure. Several north-, northeast- and northwest-striking brittle and ductile faults displace stratigraphy and further complicate stratigraphic correlation in this segment. Some of these faults host economically significant gold mineralization; a feature more common in the Hislop–Michaud segment than elsewhere along the PDDZ.

All gold deposits are structurally controlled and spatially associated with alkaline intrusive rocks; calc-alkaline intrusions are rare or absent. Some deposits, including the Ross Mine and SW zone are hosted in Timiskaming metasedimentary rocks associated with lamprophyre and albitite dikes. Deposits, such as the Buffonta, St. Andrew Goldfields and Royal Oak pits, are hosted in mafic and ultramafic metavolcanic rocks adjacent to alkalic intrusions or lamprophyre dikes. The Ludgate Lake, and Pangea deposits are hosted in syenite and mafic metavolcanic rocks. Gold occurs most commonly in disseminated sulphide minerals (mainly pyrite); however, quartz-carbonate stockwork and veinlets are still important hosts. Free gold is uncommon; most is associated with pyrite and less commonly chalcopyrite, sphalerite and galena. Hydrothermal alteration products vary in proportion with the different host rock types. For example, iron carbonate is abundant at deposits hosted by ultramafic and metasedimentary rocks, such as the Ross Mine, St. Andrew Goldfields and Royal Oak pits. However, carbonate is minor or absent at deposits hosted by syenite or mafic metavolcanic rocks, such as the Ludgate Lake and Buffonta deposits. Hematite, albite and sericite are common to all deposits; locally anhydrite, apatite, fluorite, and molybdenite are present. Widespread alteration minerals such as hematite, anhydrite and barite indicate oxidization is more prevalent in the Hislop–Michaud segment than elsewhere along the PDDZ.

The Ross Mine is an unique epizonal deposit characterized by anhydrite, gypsum, and tellurides localized in hydrothermal pipes and brittle faults (Ploeger 1978). Other deposits in this segment are hosted in predominantly ductile shear zones and mylonite zones that are locally overprinted by brittle deformation.

HARKER–HOLLOWAY SEGMENT

The Harker–Holloway segment extends from the Garrison fault in Garrison Township to the Quebec border (approximately 29 km long, *see* Figure 9.2). Couture (1991) identified north-northwest-striking faults that may represent bounding structures to segments in Quebec. Recent work by Luinstra and Benn (2000) and Berger (2000) indicate that the PDDZ is a brittle–ductile feature characterized by discrete fault planes and shear zones separating less deformed panels of rock. The entire zone is east striking, steeply south dipping and displays late reverse movement. The Ghostmount and McKenna faults are east-northeast-striking, south-dipping splay structures developed south of the PDDZ and also display late reverse movement. All gold deposits in the Harker–Holloway segment are located within the PDDZ or on the splay faults to the south. Ductile and brittle deformation are prevalent in this segment.

The Holloway and Holt–McDermott mines exploit the 2 major deposits in the segment; several subeconomic deposits and showings also occur. Deposits in this segment are hosted in tholeiitic metavolcanic rocks at or near lithological contacts. Gold occurs principally in disseminated pyrite; free gold is rare. Chalcopyrite, arsenopyrite and rare scheelite are accessory minerals in the ore zones. Quartz-carbonate stockwork is common. Iron carbonate is ubiquitous and generally increases in intensity toward the ore zones. Albite and sericite increase in intensity proximal to ore zones. Hematite is common and generally antithetic with gold tenor. Syenitic dikes at the Holt–McDermott Mine are associated with the highest grade gold in the South zone deposit. However, barren alkalic lamprophyre dikes cut the Lightning zone deposit at the Holloway Mine (Luinstra and Benn 2000). Robert (1997) classifies these deposits as syenite-associated disseminated sulphide deposits.

DISCUSSION

A model to explain the regional variations in gold mineralization styles along the PDDZ is presented in Figures 9.3 and 9.4. Different crustal levels are exposed in each segment along the PDDZ by various combinations of horizontal, vertical and rotational displacement on the bounding north-northwest faults. Thus, intrusion centred, epizonal quartz-carbonate veins and stockwork with widespread alteration haloes in the Timmins segment are expressed as deeper seated laminated quartz-carbonate veins with more restricted alteration in the Pamour segment. Similarly, disseminated sulphide mineralization, carbonate-poor deposits closely associated with alkaline plutonic rocks in the Hislop–Michaud segment are expressed as disseminated sulphide, carbonate-rich deposits distal from alkaline plutonic rocks in the Harker–Holloway segment. Deposits in the Nighthawk–Matheson segment represent mesozonal lode gold deposits remote from any type of intrusion. This model combines salient deposit classification criteria presented by Robert and Poulsen (1997) with elements of the crustal continuum model proposed by Groves et al. (1992) and the depositional model proposed by Colvine et al. (1988) to account for the variation of mineralization styles along the PDDZ. Feng and Kerrich (1990) indicated that different crustal levels were exposed in large fault-bounded blocks in the southwestern Abitibi greenstone belt based on aluminium in hornblende and other geobarometers. The observations presented in this paper indicate the large blocks can be subdivided into smaller regimes.

The role of the north-northwest-striking faults is critical to understanding these variations; however, only the Burrows–Benedict fault has been studied in any detail. Ferguson et al. (1968), Pyke (1982) and Brisbin (1997) indicate that the Burrows–Benedict fault is a brittle structure that crosscuts the PDDZ with horizontal and vertical displacement. Brisbin (1997) inferred that the east side of the fault moved up and rotated counterclockwise about a pivot somewhere south of Timmins. The Cross Lake and Hislop faults also contain brittle fault gouge and, by inference, probably record various horizontal, vertical and rotational displacements, thus exposing different crustal levels along the PDDZ. More controversial is the timing of movement on the faults. Pyke (1982) and Brisbin (1997) infer post-Paleoproterozoic movement on the Burrows–Benedict fault based on the presence of offset diabase dikes south of Timmins. However, there is evidence from other north-northwest-striking faults that this movement represents reactivation. Syenite dikes, intruded along the Hislop fault and the north-northwest-striking fault that hosts the Buffonta deposit, indicate the structures were present prior to 2678 Ma (the age of the Garrison Stock (Corfu 1993)). In many places, diabase dikes follow north-northwest-striking faults without displacement or structural disturbance suggesting the faults were pre-existing conduits for the magma.

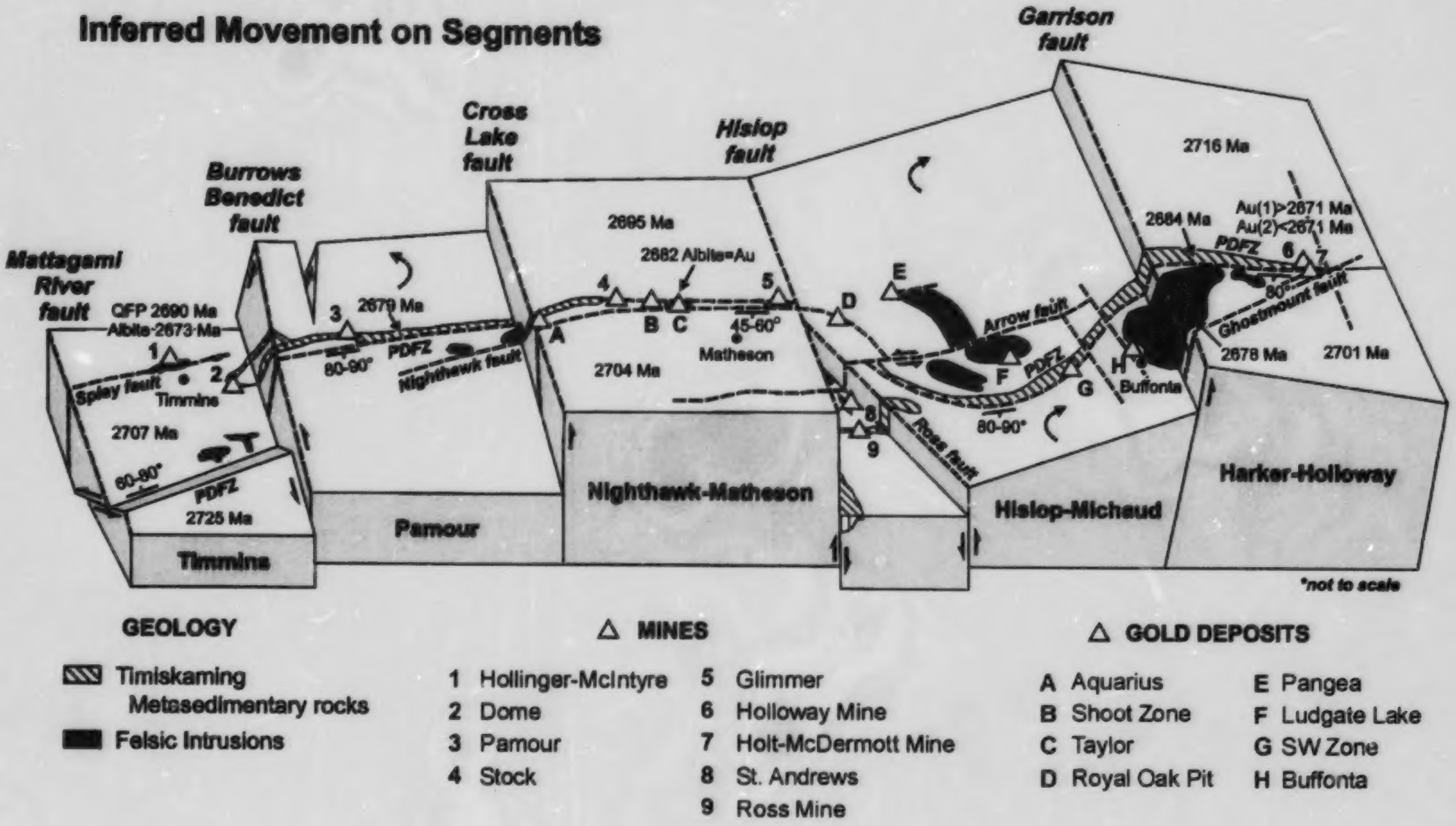
Inferred Movement on Segments
Mattagami River fault
Burrows Benedict fault
Cross Lake fault
Hislop fault
Garrison fault
QFP 2690 Ma
Albite 2673 Ma
1
2
Splay fault
Timmins
2707 Ma
60-80°
PDFZ
2725 Ma
Timmins
3
2679 Ma
80-90°
PDFZ
Nighthawk fault
Pamour
4
A
B
C
5
2695 Ma
2682 Albite=Au
45-60°
Matheson
2704 Ma
Nighthawk-Matheson
D
E
8
9
Ross fault
Arrow fault
F
PDFZ
G
80-90°
H
Buffonta
Hislop-Michaud
2716 Ma
2684 Ma
Au(1)>2671 Ma
Au(2)<2671 Ma
PDFZ
6
7
80°
Ghostmount fault
2678 Ma
2701 Ma
Harker-Holloway
*not to scale
GEOLOGY
▨ Timiskaming Metasedimentary rocks
■ Felsic Intrusions
△ MINES
1 Hollinger-McIntyre
2 Dome
3 Pamour
4 Stock
5 Glimmer
6 Holloway Mine
7 Holt-McDermott Mine
8 St. Andrews
9 Ross Mine
△ GOLD DEPOSITS
A Aquarius
B Shoot Zone
C Taylor
D Royal Oak Pit
E Pangea
F Ludgate Lake
G SW Zone
H Buffonta

Figure 9.3. Inferred movement on segments in the study area. Abbreviation: PDFZ, Porcupine–Destor deformation [fault] zone.

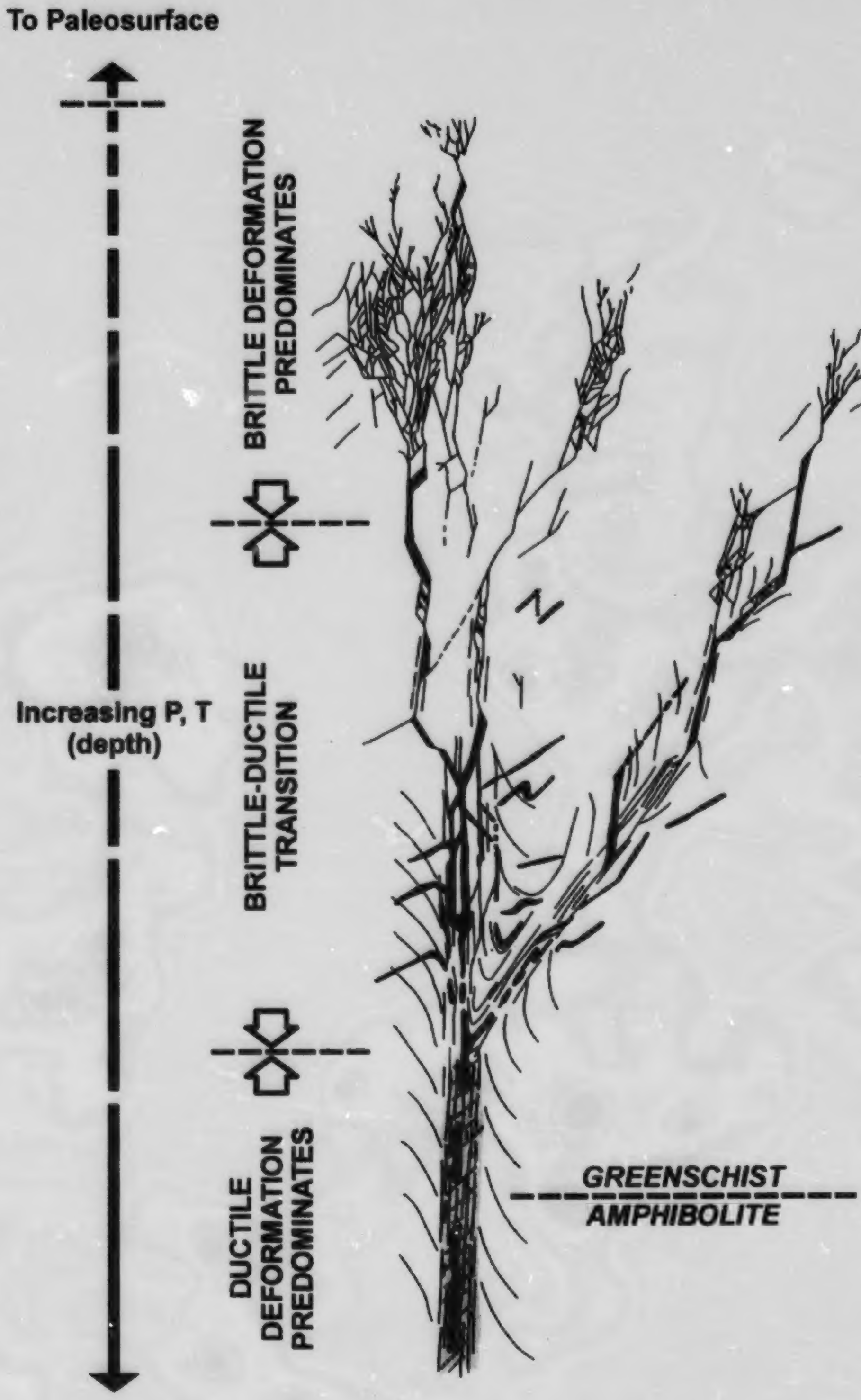
To Paleosurface
BRITTLE DEFORMATION PREDOMINATES
Increasing P, T (depth)
BRITTLE-DUCTILE TRANSITION
DUCTILE DEFORMATION PREDOMINATES
GREENSCHIST
AMPHIBOLITE

Figure 9.4. Idealized model of gold mineralization in a shear zone (*after* Colvine et al. 1988).

Finally, the Cross Lake fault and the fault that hosts the Buffonta deposit display brittle–ductile features and host gold mineralization that are overprinted by local fault gouge indicating movement was complex and probably long lived.

Several authors recognized multiple gold mineralizing events in the study area (Proudlove, Hutchinson and Rogers, 1989; Gray 1994; Brisbin 1997; Luinstra and Benn 2000; Berger and Amelin 1999). One of these events is directly linked to intrusion of albitite dikes in the Timmins segment (Melnik-Proud 1992) and in the Nighthawk–Matheson segment (Worden, Cumming and Krstic 1995). An alkalic intermineral dike at the Holloway Mine brackets gold mineralization in the Harker–Holloway segment at 2671 Ma (Luinstra and Benn 2000). Geology indicates that albitite dikes occur in each of the segments and geochronology confirms that all albitite intrusions are broadly coeval (*see* Table 9.1). The PDDZ must have tapped a common source along at least 140 km as a similar magmatic event related to gold mineralization occurs in each segment.

IMPLICATIONS FOR EXPLORATION

The variation in mineralization styles indicates that successful exploration should employ different methods and strategies in the various segments along the PDDZ. For instance, the spatial association of gold deposits with quartz-feldspar porphyry intrusions north of the PDDZ has long guided exploration in the Timmins segment. Geophysics, using combinations of airborne and ground electromagnetic, magnetic and induced polarization, can provide better target definition for disseminated sulphide mineralization deposits. These methods have been used successfully in the Nighthawk–Matheson, Hislop–Michaud and Harker–Holloway segments. The localization of gold in northerly striking brittle–ductile and ductile structures at the Aquarius deposit and in several places in the Hislop–Michaud segment require special attention to structural analysis and the search for fertile splay faults in the eastern segments. The spatial distribution and different abundances of alteration minerals in each segment can be used to guide exploration.

This paper demonstrates that albitite, a high sodium rock, occurs in all segments along the PDDZ and is closely linked with gold mineralization. Lithogeochemistry, designed to search for sodium enrichment, may prove a useful vector to ore exploration.

CONCLUSIONS

The results of detailed field mapping, compilation and research demonstrate that there is variation in styles of gold mineralization along 140 km of the PDDZ from Timmins, Ontario to Quebec. The PDDZ is divisible into 5 fault-bounded segments and a specific style of gold mineralization is predominant within a given segment. The segments are bounded by crosscutting north-northwest-striking faults that are characterized by complex and long-lived horizontal, vertical and rotational displacement. Thus, different crustal levels are exposed in each segment. Intrusion centred quartz vein arrays associated with calc-alkalic quartz-feldspar porphyry at Timmins are contrasted with disseminated sulphide deposits associated with alkalic intrusive rocks near the Quebec border and indicate multiple genesis for gold mineralization. However, coeval albitite intrusion is directly linked to 1 episode of gold mineralization all along the PDDZ and establishes a unifying link with each segment. Thus, a crustal continuum model (Groves et al. 1992) combined with different models for gold genesis (Robert and Poulsen 1997) best explains the variations in mineralization styles along the PDDZ.

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10. Project Unit 000-10. Geological Reconnaissance along Highway 66, from Matachewan to Swastika

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INTRODUCTION

A multi-year project designed to re-map and improve the geological database along Highway 66 west of Kirkland Lake was started this year (Figure 10.1). Previous mapping by Moore (1966) and Lovell (1967, 1972) outlined the major metavolcanic, metasedimentary and plutonic units. These authors mapped prior to recognition of komatiites and modern plate tectonic theory, which necessitates re-evaluation of these map areas. Jensen (1990) provided detailed data for Burt, Holmes and parts of Eby, Flavelle and Gross townships, but there are several "boundary" faults with earlier mapping that require resolution.

The map area is underlain by Neoarchean ultramafic, mafic, intermediate and felsic metavolcanic rocks, related synvolcanic intrusive rocks, clastic and chemical metasedimentary rocks. Alkalic metavolcanic rocks underlie parts of Holmes and Flavelle townships and are spatially associated with possible co-magmatic alkalic intrusions and Timiskaming assemblage metasedimentary rocks. Syenite intrusions include the Otto and Cairo stocks, as well as several smaller dikes and intrusions throughout the area. The Otto Stock, in Otto and Eby townships, is characterized by nepheline-bearing syenite, quartz syenite and includes previously unrecognized mafic and ultramafic alkalic gabbro, hornblendite and lamprophyre phases. The Cairo Stock is composed of equigranular to porphyritic syenite and quartz syenite; mafic and ultramafic phases are not known. Calc-alkaline felsic intrusions include gneiss, tonalite, quartz monzonite and granodiorite of the Round Lake batholith in the southern part of the map area. Dioritic gneiss, quartz monzonite and granodiorite of the Watabeag batholith underlie the northern parts of Holmes and Burt townships. Paleoproterozoic Matachewan swarm dikes intrude all Neoarchean rocks in the area and are composed of plagioclase porphyritic and aphyric diabase. Paleoproterozoic sedimentary rocks of the Cobalt Group unconformably overlie the Neoarchean rocks and are composed of conglomerate, argillite and sandstone.

This summer's reconnaissance was designed to identify geological problems that will be resolved by future mapping. Among the more significant efforts will be revision of the Neoarchean stratigraphy, including separation of komatiitic rocks in the area. The stratigraphy will be correlated with tectonic assemblages erected by Ayer et al. (1999), with emphasis on contact relationships between the units. The relationship between the alkalic metavolcanic and Timiskaming assemblage metasedimentary rocks will be established and material for geochronology (using zircons) will be collected. A synthesis of the geochemistry for each assemblage will be completed using analyses from previous mapping supplemented with material collected by the author. There are inconsistencies among the various earlier mapping efforts as to the location and names of the major structures in the area. Future mapping will attempt to resolve the nature and location of the structural features in the area with attention to the relationship of gold mineralization to the Larder–Cadillac deformation zone and related fault systems. Numerous north-northwest-striking faults, the most prominent being the Cross Lake fault, crosscut the geology. These are most likely Archean structures that were reactivated during the Paleoproterozoic as numerous Matachewan dikes intruded these structures. Post Proterozoic reactivation of structures is indicated in a few places where Cobalt Group sedimentary rocks are tilted and display penetrative north-

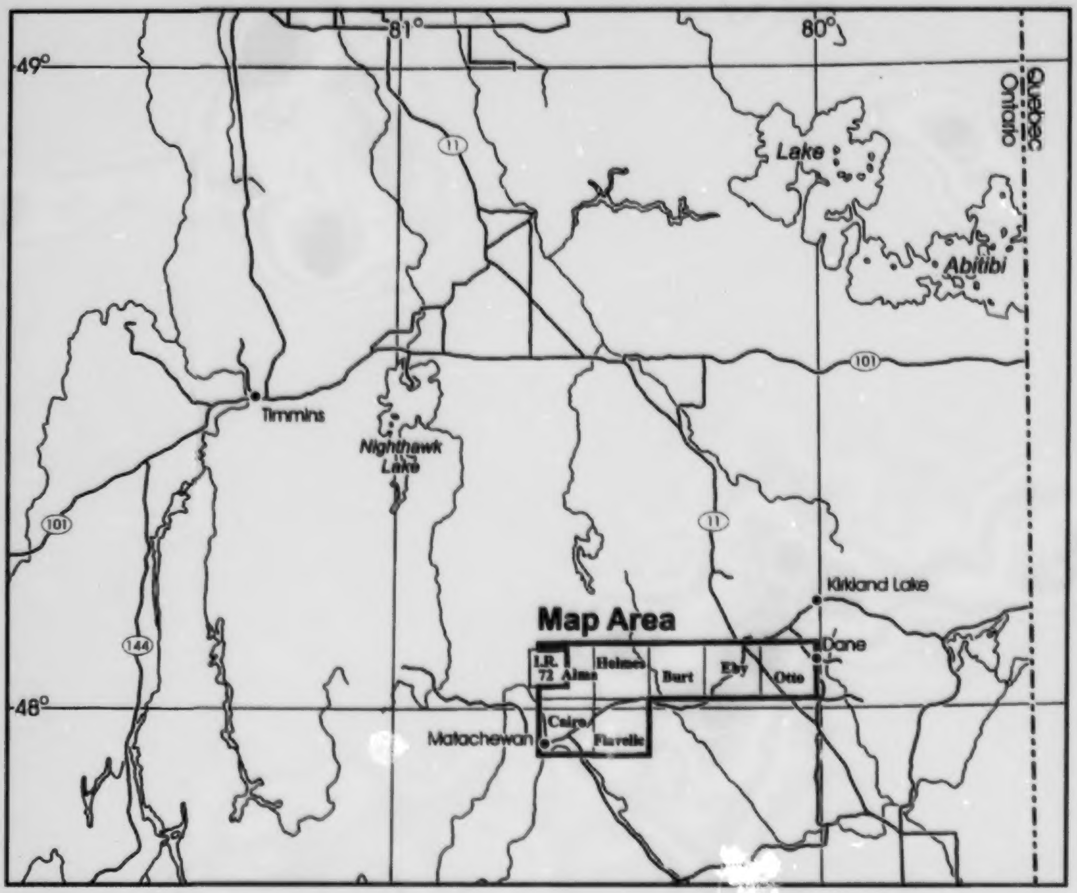

Figure 10.1. Location map for the area of the Highway 66 reconnaissance project.

striking foliation. This deformation has apparently also reactivated the Larder–Cadillac deformation zone in Burt Township (G. Meyer, Resident Geologist, Kirkland Lake, personal communication, June 2001) and future mapping will locate and document the nature of this deformation.

Paleoproterozoic sedimentary rocks of the Huronian Supergroup occur in parts of Burt, Holmes, Flavelle and Cairo townships. Previous mapping correlated all these rocks with the Gowganda Formation of the Cobalt Group. The author observed sandstone–arkose units up to 10 m thick in central Burt Township, which is inconsistent with the typical Gowganda Formation members as described by Johns (1985). It is probable that members of the overlying Lorrain Formation occur in the map area.

The Consolidated Matachewan and Young–Davidson mines exploited gold mineralization in Powell Township west of the map area. Consequently, gold has been the most sought after mineral in the Highway 66 area. Barite and fluorite veins within the Cairo Stock occur at Browning Lake and regional till sampling data indicate anomalous barium and barite elsewhere in the map area (Bajc 1997). Rock samples collected for the Ontario Treasure Hunt rock properties project indicates komatiitic metavolcanic rocks occur in Alma Township (Deschamps 2000). These rocks are potential hosts to copper-nickel sulphide mineralization. The mafic and ultramafic phases of the alkalic intrusions are commonly enriched in platinum group elements (PGE) and the hornblendite, alkalic gabbro and lamprophyre of the Otto Stock are potential host rocks for this type of mineralization.

Mineralized and representative rock samples collected during this reconnaissance were submitted to the Geoscience Laboratories in Sudbury for analysis. Table 10.1 presents assay data results. Anomalous gold, palladium and platinum values were detected a selected chip sample (01-BRB-019) collected across 50 cm of malachite-stained lamprophyre and/or hornblendite along a roadcut on Highway 11 in Otto Township. This rock was previously mapped as "greenstone" and indicates that re-mapping of the Otto Stock is necessary and that ultramafic phases of the stock are potential hosts for PGE mineralization.

Table 10.1. Assay results for project 000-10.

Sample No.	Rock Type	UTM		Township	Au (ppb)	Pd (ppb)	Pt (ppb)	Ag (ppm)	Cu (ppm)	Ni (ppm)
		Easting	Northing							
01-BRB-006a	hornblendite	573171	5324800	Otto	<5	<8	<8	2	<1	67
01-BRB-006b	hornblendite	573171	5324800	Otto	<5	9.16	<8	NA	NA	NA
01-BRB-015	barite + fluorite	530660	5316972	Cairo	<5	<8	<8	<1	11	6
01-BRB-016	alkali basalt	538571	5317953	Holmes	<5	<8	<8	NA	NA	NA
01-BRB-018	trachyte	538245	5320725	Holmes	13.57	<8	<8	NA	NA	NA
01-BRB-019	hornblendite	563378	5323813	Otto	169.8	164.16	54.68	12	6830	68
01-BRB-020	intermediate alkali flow	564062	5327921	Eby	<5	<8	<8	NA	NA	NA

N.A., not analyzed; UTM coordinates: zone 17, NAD 83 datum

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11. Project Unit 99-026. Mineralogy of Pyroxene, Amphibole and Mica in Syenitic Rocks of the Porcupine–Destor Deformation Zone near Matheson, Ontario

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INTRODUCTION

We describe the occurrence and composition of the principal mafic minerals in a suite of small intrusions of syenite and related rocks that are closely associated with gold mineralization in the Porcupine–Destor deformation zone, near and east of Matheson, Ontario. The intrusions studied are, from east to west, the Iris, Garrison, Emens Lake, Ludgate and Pangea intrusions (Figure 11.1).

The objectives of this paper, which constitutes part of an MSc project at the University of Ottawa and an Ontario Geological Survey–University of Ottawa Graduate Thesis Agreement, are 1) to describe the occurrence, textural relationships and paragenesis of the principal ferromagnesian minerals in syenite intrusions; 2) to delineate the mineral chemistry and compositional evolution of these minerals in order to gain insight into the redox conditions that prevailed during crystallization; and 3) to characterize the postmagmatic alteration of these minerals. This is a continuation of work that was initiated in 1999 (Pigeon, Lalonde and Berger 1999, 2000).

Mineral analyses were carried out by wavelength-dispersive X-ray spectrometry on a Cameca electron microprobe at the Geoscience Laboratories, Ontario Geoservices Centre, Sudbury. Operating conditions were set to 20 kV and 20 nA using a beam diameter of 3 to 12 µm, the diameter dependent upon the mineral analyzed. Counting times varied from 10 to 15 seconds per element. All analyses were corrected with the PAP procedure.

Pyroxene formulae and nomenclature are based on the recommendations of the International Mineralogical Association (IMA) (Morimoto 1989). Estimations of Fe^{2+} to Fe^{3+} contents were done by charge-balance considerations. Amphibole formulae were calculated on the basis of 13 cations (Si^{4+}, Al^{3+}, Cr^{3+}, Ti^{4+}, Fe^{2+}, Fe^{3+}, Mg^{2+}, Mn^{2+}) and assuming that (OH^-, Cl^-, F^-) equal 2. Assignments of cations and nomenclature of the amphiboles were done according to the current IMA recommendations (Leake et al. 1997). Here again, estimations of Fe^{2+} to Fe^{3+} contents were done by charge-balance considerations. Micas were calculated on the basis of 12 anions [10 oxygens + 2 (OH^-, Cl^-, F^-)]. Classification and site assignments for the micas were also done according to current IMA recommendations (Rieder et al. 1998). The following results are based on 23 analyses of pyroxene from 10 different samples, 24 analyses of amphibole from 12 samples, and 19 analyses of mica from 15 samples.

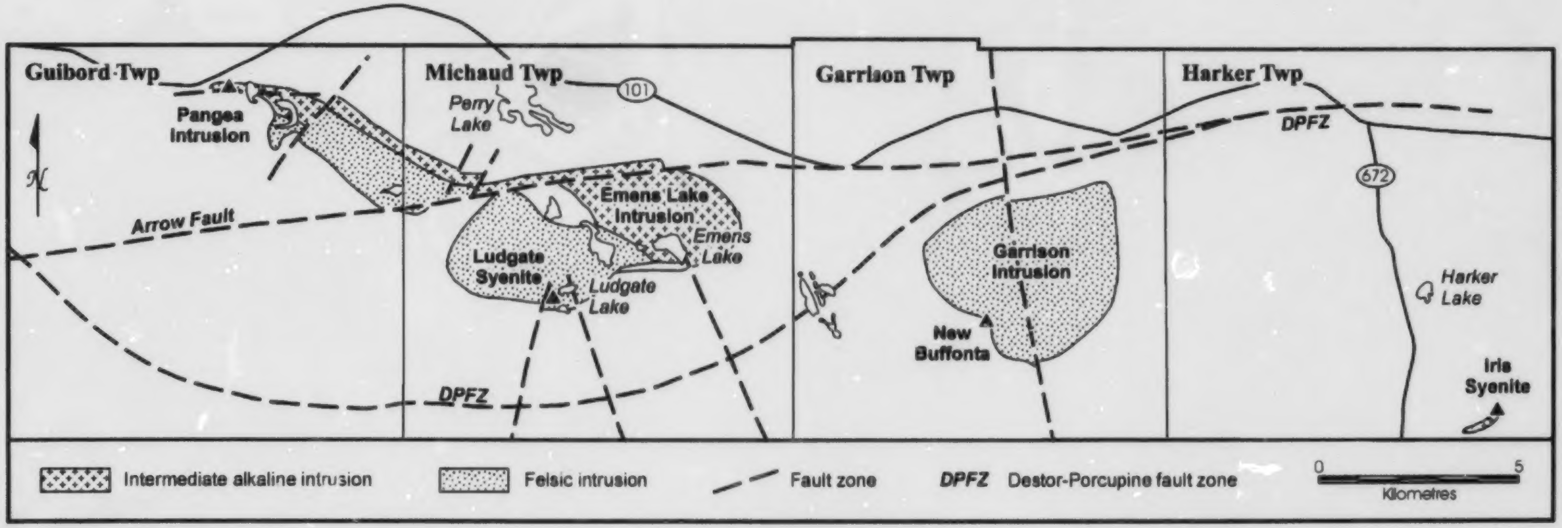
Guibord Twp
Michaud Twp
Garrison Twp
Harker Twp
N
Pangea Intrusion
Perry Lake
101
Arrow Fault
Emens Lake Intrusion
Emens Lake
Ludgate Syenite
Ludgate Lake
DPFZ
Garrison Intrusion
New Buffonta
672
Harker Lake
Iris Syenite
Intermediate alkaline intrusion
Felsic intrusion
Fault zone
DPFZ Destor-Porcupine fault zone
0
5
Kilometres

Figure 11.1. Location map of study area.

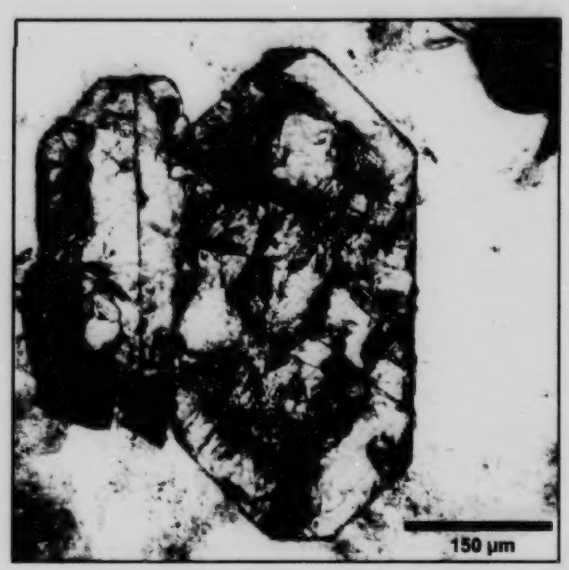

Figure 11.2. Basal section of euhedral crystals of diopside in syenite from the Iris intrusion. Plane-polarized light.

MINERALOGY AND MINERAL CHEMISTRY

Pyroxene

Pyroxene is found in all the intrusions studied, however, in the Garrison intrusion, pyroxene occurs only in minor amounts (<1%), and, in the Ludgate intrusion, only one sample contains pyroxene.

In the Iris intrusion, pyroxene is more common in the hornblendite and diorite units (20 to 40%), but is also present as a minor phase in the medium-grained syenite unit (5 to 10%). Pyroxene from the hornblendite and medium-grained syenite is commonly subhedral to euhedral. In the diorite unit, it is anhedral to subhedral. When subhedral or euhedral, the pyroxene crystals show long prismatic or equant basal sections, suggesting a primary magmatic origin (Figure 11.2).

The pyroxene in the hornblendite and medium-grained syenite is fresh with only minor alteration. In the diorite unit, pyroxene is commonly rimmed by amphibole. In all rocks, the pyroxene is light green and displays minor or no pleochroism. Three representative analyses of pyroxene from the Iris and other intrusions are listed in Table 11.1. All analyses of pyroxene from the Iris intrusion plot in the diopside field of the pyroxene quadrilateral diagram (Figure 11.3a).

Fresh pyroxene is not common in the samples from the Pangea and Emens intrusions. When present in these rocks, the pyroxene is found in the centre of amphibole clusters, suggesting that the amphibole replaced the primary pyroxene. In the Pangea intrusion, pyroxene is present in hornblendite and melanosyenite units; and in the melanosyenite unit in the Emens intrusion. Pyroxene occurs as anhedral crystals that are light green with minor or no pleochroism. All pyroxene from the Pangea intrusion is diopside, however, the pyroxene in the Emens intrusion is distinctly more sodic (Figure 11.3b) and corresponds to aegirine-augite.

Table 11.1. Mineral chemistry of representative pyroxene, amphibole and mica.

	Pyroxene			**Amphibole**				**Mica**	
Intrusion	**Iris** [a]	**Iris** [a]	**Emens** [b]	**Pangea** [c]	**Iris** [d]	**Pangea** [e]	**Ludgate** [f]	**Iris** [g]	**Emens** [h]
Sample No.	**125-1-2**	**126-1-1**	**45-1-1**	**009-21**	**126-22**	**035-41**	**088-32**	**069-32**	**086-21**
SiO_2	50.62	49.31	53.24	41.67	40.33	52.53	55.62	35.39	36.83
TiO_2	0.59	0.73	0.03	2.86	2.30	0.05	0.08	3.04	2.29
Al_2O_3	3.24	4.26	1.37	10.40	13.40	1.87	0.41	14.97	13.92
Cr_2O_3	0.00	0.02	0.02	0.01	0.00	0.03	0.01	0.00	0.00
MgO	14.19	13.49	6.67	8.45	12.51	14.33	10.29	11.56	12.61
CaO	23.13	23.17	11.02	10.40	11.90	11.90	0.91	0.06	0.02
MnO	0.17	0.21	0.16	0.21	0.20	0.48	0.12	0.98	0.62
FeO	4.42	4.49	0.98	14.70	10.66	11.55	7.89	20.36	19.45
Fe_2O_3 [i]	3.29	3.67	19.22	7.04	1.94	3.69	15.77	–	–
Na_2O	0.33	0.32	7.90	2.40	2.59	0.53	6.60	0.08	0.06
K_2O	0.01	0.00	0.02	0.67	1.59	0.20	0.09	9.35	9.77
F	0.00	0.08	0.04	0.03	0.12	0.07	0.14	0.22	0.29
Cl	0.01	0.00	0.00	0.02	0.02	0.00	0.03	0.01	0.00
H_2O [j]	–	–	–	1.97	1.95	2.02	2.00	3.79	3.78
O=F	0.00	-0.03	-0.02	-0.01	-0.05	-0.03	-0.06	-0.09	-0.12
O=Cl	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
Total	100.00	99.72	100.65	100.81	99.46	99.22	99.90	99.72	99.51
Based on:	4 cations			24 anions and 13 cations				12 anions	
Si^{4+}	1.879	1.841	1.983	6.266	6.023	7.673	8.027	2.722	2.821
Ti^{4+}	0.016	0.020	0.001	0.323	0.258	0.005	0.009	0.176	0.132
Al^{3+}	0.142	0.187	0.060	1.843	2.358	0.322	0.070	1.357	1.257
Cr^{3+}	0.000	0.001	0.001	0.001	0.000	0.003	0.001	0.000	0.000
Mg^{2+}	0.785	0.751	0.370	1.894	2.785	3.120	2.214	1.326	1.440
Ca^{2+}	0.920	0.927	0.440	1.676	1.904	1.862	0.141	0.005	0.002
Mn^{2+}	0.005	0.007	0.005	0.027	0.025	0.059	0.015	0.064	0.040
Fe^{2+}	0.137	0.140	0.030	1.848	1.332	1.411	0.952	1.310	1.246
Fe^{3+}	0.092	0.103	0.539	0.797	0.218	0.406	1.713	–	–
Na^+	0.024	0.023	0.570	0.700	0.750	0.150	1.847	0.012	0.009
K^+	0.000	0.000	0.001	0.129	0.303	0.037	0.017	0.917	0.955
F^-	0.000	0.009	0.005	0.014	0.057	0.032	0.064	0.054	0.070
Cl^-	0.001	0.000	0.000	0.005	0.005	0.000	0.007	0.001	0.000

Notes: *a*, diopside; *b*, aegirine-augite; *c*, magnesiohastingsite; *d*, pargasite; *e*, actinolite; *f*, magnesioriebeckite; *g*, phlogopite; *h*, annite; *i*, calculated Fe^{2+} and Fe^{3+} values; *j*, calculated assuming OH + Cl + F = 2.

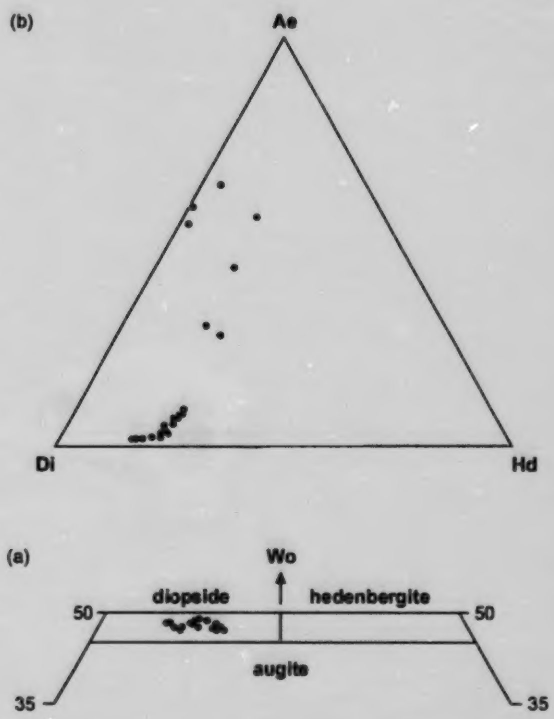

Figure 11.3. Composition of pyroxenes from all the studied intrusions plotted on a) part of the pyroxene quadrilateral, and b) the aegirine-diopside-hedenbergite triangular diagram.

Pyroxene at the Ludgate intrusion was observed in a single sample of syenite. This pyroxene occurs as anhedral to subhedral crystals that are fresh and that display a light pleochroism from yellowish green to pale green. Crystal size varies from approximately 0.5 to 1 mm. Pyroxene at the Ludgate intrusion is aegirine-augite.

Samples of the Garrison intrusion contain minor (<1%), but ubiquitous, small (<1 mm) anhedral pyroxene crystals. The pyroxene is fresh in appearance and displays distinct pleochroism from light yellowish green to darker green. Pyroxene at the Garrison intrusion is aegirine-augite.

Amphibole

Amphibole is a major phase in the mafic rocks of the Iris and Pangea intrusions, and a minor, but ubiquitous, phase in the Garrison and Ludgate intrusions.

Amphibole from the Pangea intrusion is abundant in the hornblendite (~15 to 40%) and melanosyenite units (~15 to 20%). In these 2 rock units, the amphibole is both a primary magmatic phase and a later alteration product. Primary amphibole occurs predominantly as small (~0.5 to 0.8 mm) anhedral crystals displaying light to dark olive green pleochroism. Large (2 to 8 mm) anhedral megacrysts displaying light olive green to brownish orange pleochroism are common. These megacrysts are interpreted to have formed late in the crystallization sequence since they commonly contain numerous inclusions of apatite, magnetite and pyroxene. Secondary deuteric actinolite commonly replaces subhedral to euhedral crystals of pyroxene. A representative analysis of a megacryst from the hornblendite unit, and 3 amphiboles from other intrusions, are given in Table 11.1. The megacrysts are

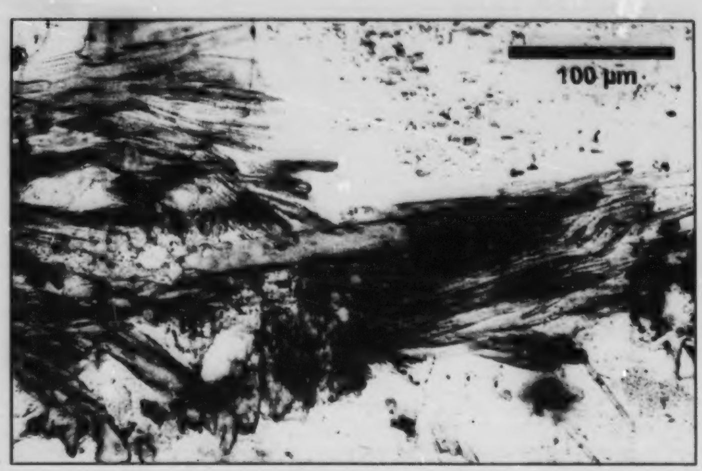

Figure 11.4. Subhedral acicular crystals of magnesioriebeckite in syenite from the Ludgate intrusion. Plane-polarized light.

magnesiohastingsite and tschermakite. Hastingsite and ferrotschermakite were also identified in the Pangea intrusion.

Amphibole is abundant in the hornblendite (~30 to 50%) and the diorite (~15%) units from the Iris intrusion, and is a primary magmatic mineral in both cases. In the diorite, the amphibole crystals are small (0.5 to 0.8 mm), anhedral and light olive green. In the hornblendite unit, amphibole occurs as large (2 to 8 mm) subhedral megacrysts with numerous inclusions of apatite, magnetite, pyroxene and plagioclase which is evidence of late magmatic crystallization. The megacrysts have typically light to dark olive green to brownish orange pleochroism. The small anhedral amphibole crystals of the diorite unit were classified as hastingsite, and the megacrysts in the hornblendite unit vary in composition from pargasite to magnesiohastingsite.

Amphibole in rocks of the Garrison intrusion occurs as small (0.5 to 1 mm), anhedral to subhedral crystals that account for 5 to 10 % of the rock. This amphibole has light yellowish green to light green pleochroism. Both richterite (sodic-calcic group) and magnesioriebeckite (sodic group) were identified in the Garrison intrusion. These sodium-rich amphiboles most likely crystallized from a late sodium-enriched deuteric fluid.

Amphibole in the Ludgate intrusion occurs as small (0.2 to 0.5 mm), subhedral to euhedral acicular crystals (Figure 11.4). The pleochroism varies from light blue to bluish green and purplish blue. Minor crystals of larger (0.8 to 1 mm) anhedral bluish green amphibole are also present. The amphibole from the Ludgate syenite is magnesioriebeckite.

Mica

Biotite is a common mineral in the Emens (20 to 30%) and Pangea (15 to 20%) intrusions. However, no biotite was identified in the Garrison and Ludgate intrusions, and only one sample from the Iris intrusion contained minor amounts of biotite (<1%). Biotite in the samples of the Emens and Pangea intrusions occurs as small (0.5 to 1 mm), anhedral crystals that commonly contain numerous small inclusions of acicular rutile crystals. In general, the crystals are fresh, but chlorite alteration is common in the samples from the Pangea intrusion. Pleochroism varies from light olive green to dark green to brown. Biotite crystals in the Iris intrusion are small (0.5 to 0.8 mm), anhedral and chloritized. The pleochroism varies from light brown to dark brown.

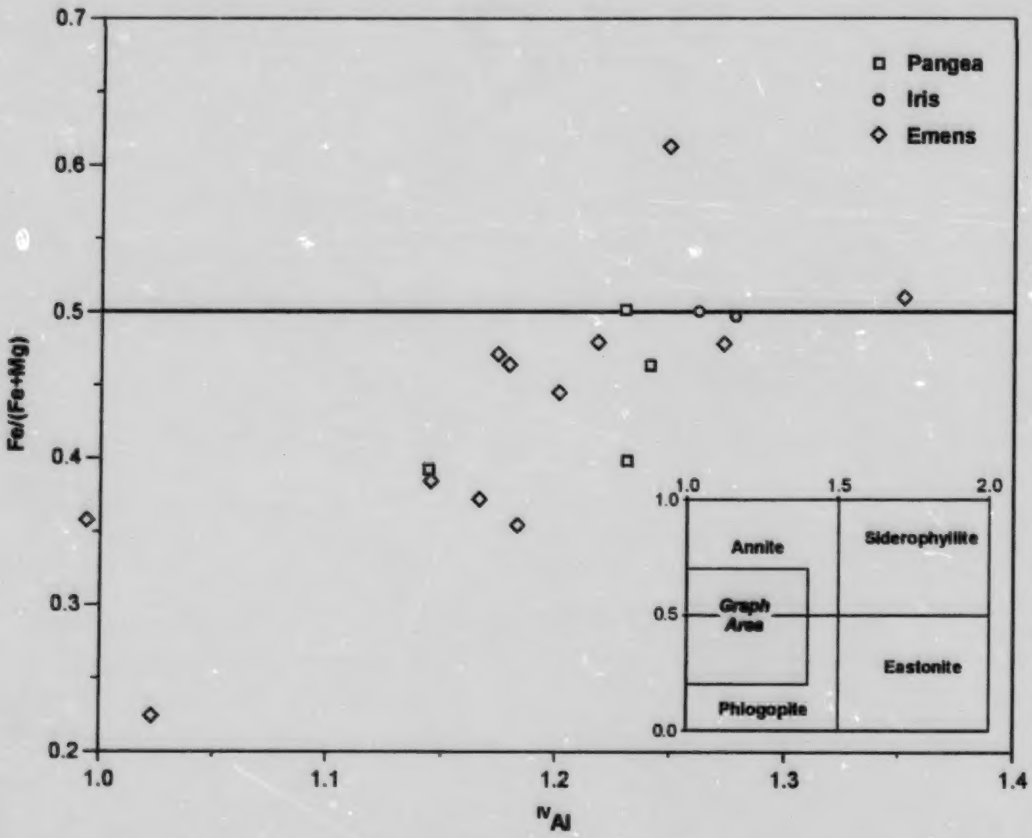

Figure 11.5. Composition of trioctahedral micas from the Pangea, Iris and Emens intrusions plotted on part of the phlogopite-annite-eastonite-siderophyllite quadrilateral diagram.

Two representative analyses of mica are given in Table 11.1. Most mica analyses, apart from 4 analyses described below, are phlogopite (Figure 11.5) in the sense of the IMA nomenclature for the mica group [i.e., Fe/(Fe+Mg) < 0.5]. One analysis from the Emens intrusion plotted within the annite field and 3 analyses plotted in the annite field on the border with the phlogopite field.

DISCUSSION

Our preliminary study of the ferromagnesian silicate minerals in the syenitic rocks of the Porcupine–Destor deformation zone allows us to determine a general paragenetic sequence for these rocks. In general, calcium-rich clinopyroxene is the first mafic mineral to crystallize. It is a primary magmatic phase and has a magnesium-rich composition (diopside) despite whole-rock compositions that are moderately iron rich. This leads us to postulate that, at the time of crystallization, the iron was most likely present as Fe^{3+} because of oxidizing conditions in the melt and, therefore, the iron partitioned into oxide mineral phases, such as magnetite or hematite, rather than mafic silicate minerals. Sodic pyroxene is also observed as a primary magmatic phase in some of the intrusions, indicating that some of the magmas achieved relatively alkaline compositions.

Amphibole is also observed as a primary magmatic phase in numerous units of the suite. The composition of this primary amphibole is variable and corresponds to pargasite, hastingsite, magnesiohastingsite, tschermakite and ferrotschermakite. Secondary amphiboles are also present. These include deuteric actinolite and sodic-calcic and sodic amphiboles, such as richterite and magnesioriebeckite. These sodium-rich amphiboles demonstrate the presence of late sodium-rich volatiles, a feature common in alkaline intrusions.

Trioctahedral micas in the studied rocks are all magnesium rich, again, possibly a consequence of oxidizing conditions. These micas, phlogopites in the sense of the IMA, are for the most part late-magmatic or post-magmatic phases. In many instances, they replace earlier pyroxenes or amphiboles. In many rocks, they coexist with unidentified accessory barium sulphates (most likely barite), once again, evidence of late oxidation.

Our initial findings indicate that ferromagnesian minerals in the syenitic rocks of the Porcupine–Destor deformation zone are directly comparable in paragenesis and mineral chemistry with those of similar syenitic rocks of the Larder–Cadillac deformation zone further to the south, where magmatic and postmagmatic oxidation have been well documented (Rowins , Lalonde and Cameron 1991; Lévesque 1994). Given the close spatial association of these intrusions with the gold mineralization along both fault zones; our current efforts on the intrusive rocks in the area of the Porcupine–Destor deformation zone are focussed on documenting the relative redox state under which the magmas evolved by means of mineral–chemical studies. These studies will help to better evaluate the potential contribution these magmas may have made to the gold mineralization process.

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12. Project Unit 00-042. Emplacement and Deformation History of the Kenogamissi Batholith and Surrounding Swayze Greenstone Belt

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INTRODUCTION

The Archean Kenogamissi batholith is a large granitoid complex situated at the boundary between the Abitibi and Swayze greenstone belts. The Abitibi and Swayze belts are contiguous and connected by narrow corridors of metavolcanic and metasedimentary rocks that wrap around the northern and southern margins of the Kenogamissi batholith (Ayer and Trowell, this volume, *see* Figure 4.1). The southern boundary of the Swayze greenstone belt corresponds to the Ramsey–Algoma granitoid complex (2727 +11/–9 Ma) and the northern boundary is marked by the Nat River granitoid complex (no age available). In the west, the Swayze greenstone belt is truncated by the Kapuskasing structural zone, a Late Archean uplift that exposes lower to middle continental crust. The spatial contiguity of the Abitibi and Swayze greenstone belts, as well as comparable lithologies (e.g., Timiskaming assemblage), strongly suggest that the Swayze greenstone belt may be the southwest extension of the Abitibi greenstone belt (Heather 1993).

The western part of the Kenogamissi batholith, and the supracrustal rocks that surround the batholith, are the subjects of this ongoing study, which is supported under an Ontario Geological Survey–University of Ottawa Collaborative Project Agreement. The work is intended to provide a model for the emplacement of the batholith and to demonstrate the role of its emplacement in the regional structural evolution and accompanying gold mineralizing events. Geochemical analyses of the plutonic rocks are also being used to place constraints on their petrogenetic origin and geodynamic significance. Ancillary work involving the authors of this report includes geochronological studies of the granitoid rocks in collaboration with the Royal Ontario Museum; and gravity data collection and gravity modelling of the shape of the batholith at depth. The gravity work is being carried out by a PhD student (A. Peschler) at the University of Ottawa, under the supervision of W.R. Roest (Geological Survey of Canada–Ottawa) and K. Benn. Final geochronological and gravity modelling results are expected in early 2002.

Only the western part of the Kenogamissi batholith, which represents an area of approximately 2000 km^2, has been mapped in detail, therefore, this project concentrates on the southwestern lobe of the batholith (Figure 12.1). This lobe consists of 3 main units; from oldest to youngest, they are hornblende diorite, hornblende tonalite and biotite granodiorite. The relative ages of the 3 units have been determined from field relationships (Heather, Shore and Van Breeman 1996). The outcrop pattern and internal structure of the western part of the Kenogamissi batholith resembles a west-plunging fold (*see* Figure 12.1).

The present study has documented 2 major deformation events (D_1 and D_2). Early north-trending F_1 folds are refolded by a later family of east-trending F_2 folds. Internal structures of the Kenogamissi batholith also record the D_1 and D_2 events. The dome-and-basin structure of the eastern Swayze greenstone belt and the Kenogamissi batholith is interpreted to be the result of interference (cross folding) between the F_1 and F_2 folds.

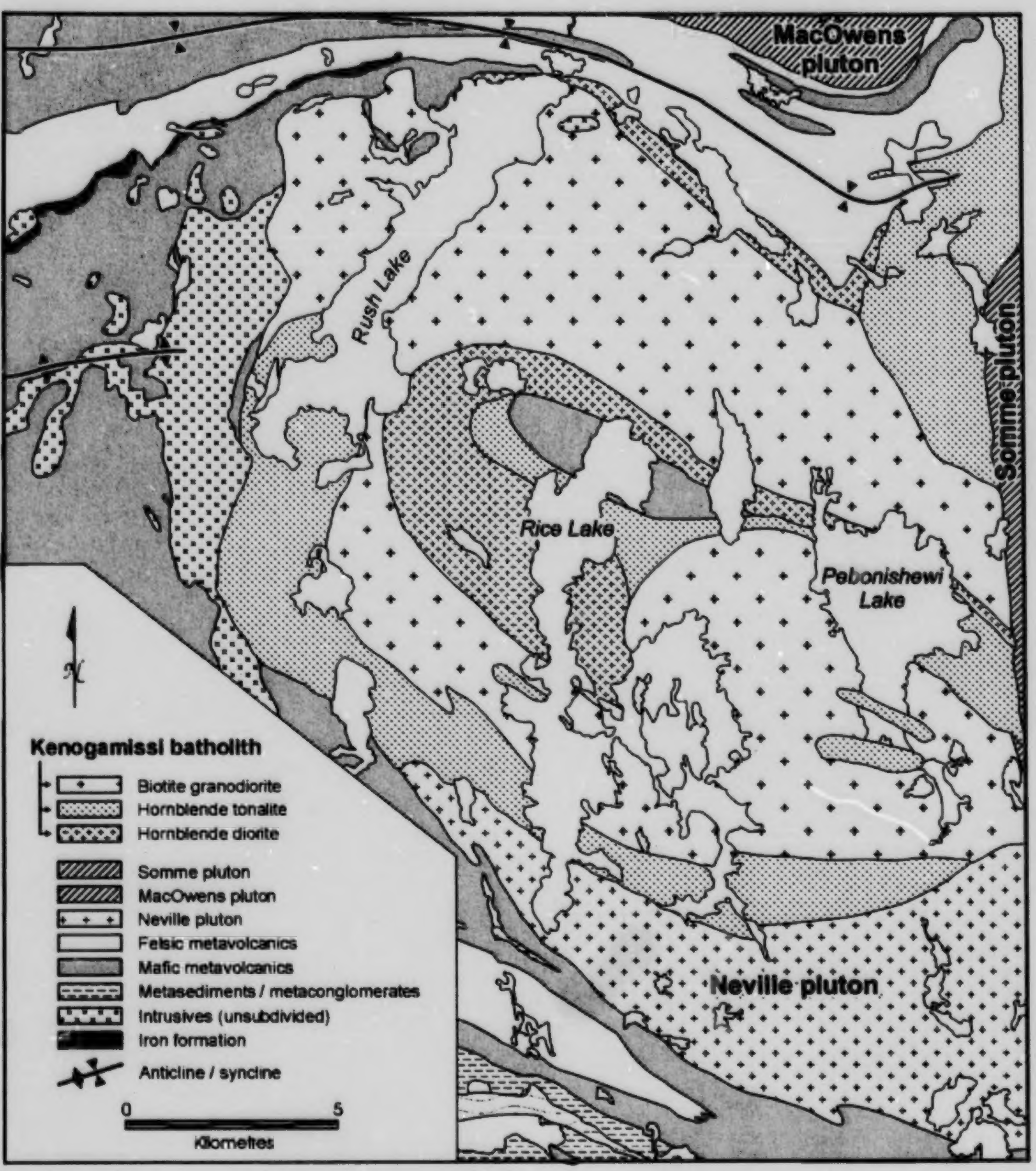
MacOwens pluton
Rush Lake
Somme pluton
Rice Lake
Pebonishewi Lake
Neville pluton
N
Kenogamissi batholith
Biotite granodiorite
Hornblende tonalite
Hornblende diorite
Somme pluton
MacOwens pluton
Neville pluton
Felsic metavolcanics
Mafic metavolcanics
Metasediments / metaconglomerates
Intrusives (unsubdivided)
Iron formation
Anticline / syncline
0
5
Kilometres

Figure 12.1. Overview of the main study area. The Neville pluton may be the strongly deformed equivalent of the hornblende tonalite.

WORK COMPLETED

A first field campaign was carried out between August and September 2000. During that campaign, 204 outcrops were mapped and sampled, mainly in the granitoid units, but also in the surrounding greenstone belts. Preliminary results were presented by Becker and Benn (2000).

Investigations of thin sections that were cut according to the mesoscopic-scale (visible in hand specimen) fabric and/or the magnetic fabric of samples have been completed and results are presented below. Maps of sample localities, structural and magnetic data from the first field campaign have been compiled.

Between June and August 2001, the second field campaign concentrated on the northern part of the Kenogamissi batholith and the greenstone belts to the west of the batholith. In total, 200 outcrops were studied and oriented samples were collected for the preparation of thin sections and for magnetic measurements. In the Swayze greenstone belt, field mapping concentrated on documenting deformational features of the 2 folding events. Inconsistencies in the structural data of the most recent geological maps (Heather 1999) suggested that previously unrecognized D_1 structures might be present in the strain shadow of the Kenogamissi batholith; this will be discussed below. In the granitoid rocks of the Kenogamissi batholith, the mapping of structural elements was enlarged from the 2000 field campaign and diamond-drill cores for the magnetic fabric analysis were collected at numerous outcrops to complete and enlarge the already existing sample grid.

STRUCTURAL GEOLOGY OF THE GREENSTONE BELTS

Previous mapping and structural analysis of the Swayze greenstone belt documented multiple generations of structures (Heather 1993; Heather, Shore and Van Breeman 1995, 1996); however, 2 major generations of structures control the overall architecture of the belt.

D_1 Structures

D_1 structures are represented by early north-trending folds. Outcrop-scale evidence for the F_1 folds is only locally preserved as they have been largely overprinted by later deformation. Photo 12.1 shows a F_1 fold hinge preserved in the banded iron formation west of the batholith (BIF in Figure 12.1).

D_2 Structures

Two regional-scale F_2 folds are amongst the most prominent D_2 structures in the study area: 1) the Brett Lake syncline, which infolds supracrustal rocks into the west-central part of the Kenogamissi batholith; and 2) the Woman River anticline, extending from the supracrustal rocks into the southwestern lobe of the batholith. The fold structures are subparallel with a general east strike and the Woman River anticline fold hinge plunges to the west (*see* Figure 12.1).

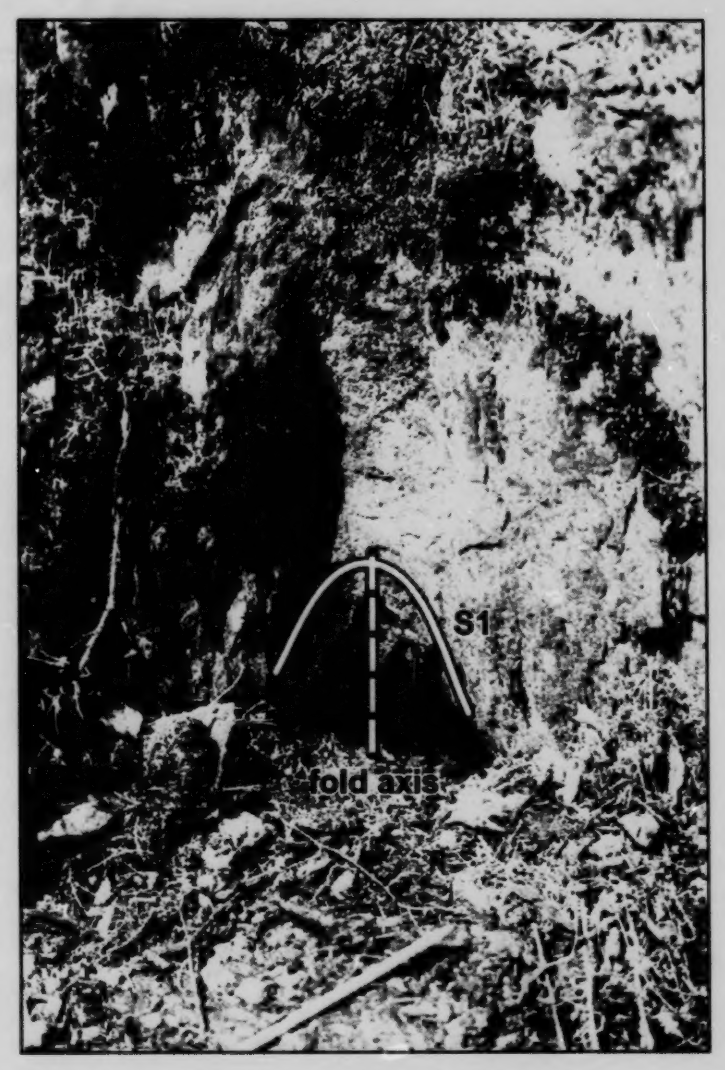

Photo 12.1. F_1 fold hinge in banded iron formation (BIF) west of the Kenogamissi batholith (pencil as scale in lower centre points north).

STRUCTURAL GEOLOGY OF THE KENOGAMISSI BATHOLITH

The distribution of the lithological units in the Kenogamissi batholith were mapped by previous workers (Heather 1999). Field work for this project consisted of mapping the mesoscopic-scale fabrics in the granitoids, and collecting oriented 25 mm diameter diamond-drill cores for the purpose of measuring the anisotropy of magnetic susceptibility (AMS) for a large number of outcrops. The AMS usually is controlled by the preferred orientations of iron-rich minerals in the rock specimens. The principal axes of the AMS ellipsoid can be used to infer the orientations of the foliation and lineation defined by the iron-rich minerals (biotite ± hornblende ± Fe-Ti oxides (presumably magnetite)). We interpret the fabrics to record the deformation that has affected the plutonic units as they were being emplaced and deformed in the magmatic state and then in the plastic state as the solidified rocks cooled from the solidus. The AMS

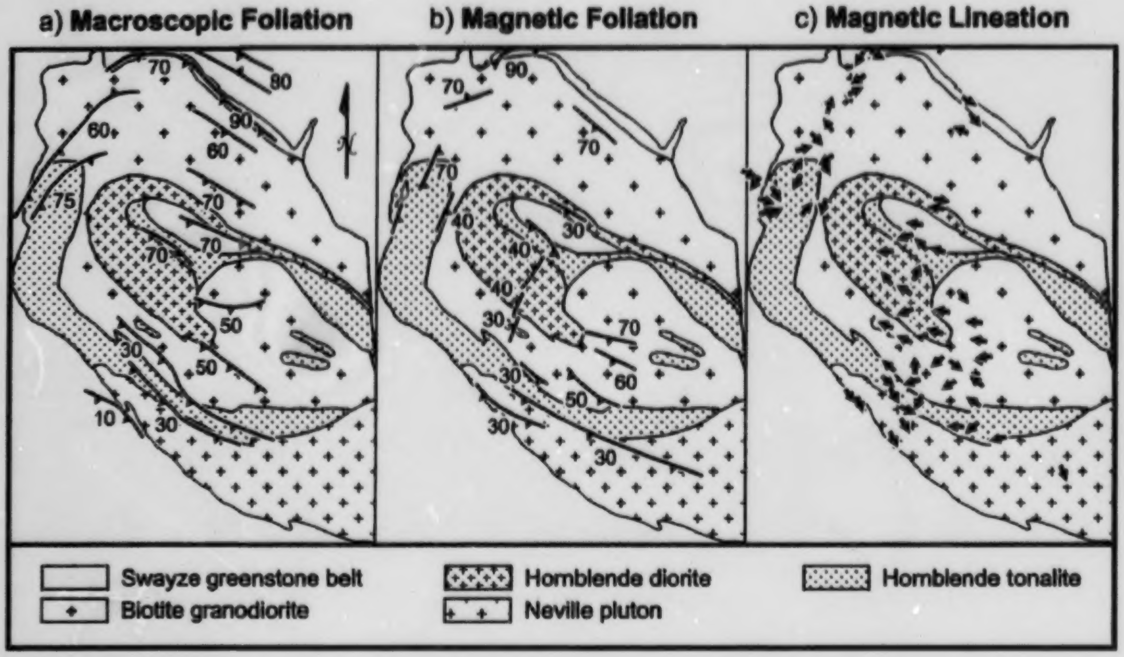
a) Macroscopic Foliation b) Magnetic Foliation c) Magnetic Lineation

Figure 12.2. a) Maps of the mesoscopic-scale foliation; b) traces of the magnetic foliation; and c) orientation of the magnetic lineation.

measurements were performed at the University of Ottawa on a KLY-2 Kappabridge instrument. The data from the 2001 field season have not yet been analyzed; therefore, we discuss the main results arising from mapping and sampling completed during the 2000 field season.

Mesoscopic-Scale Fabric

The hornblende diorite and hornblende tonalite units of the Kenogamissi batholith preserve a well expressed mesoscopic foliation defined mainly by aligned hornblende crystals and occasionally by feldspar crystals. The biotite granodiorite only shows a strong mesoscopic foliation close to the batholith margin where it is strongly deformed. The foliation in the 3 units strike northeast. The foliation has shallow to moderate southward dips in the south part of the batholith, and the dips steepen towards the north part (Figure 12.2a). Only in the western marginal areas of the biotite granodiorite and hornblende tonalite are foliations margin parallel. The margin parallel orientation may have originated during pure shear of the expanding granitoid body against the surrounding host rock. In the northern and southern marginal areas, the granitoid rocks are strongly deformed and are locally mylonitic. Oriented thin sections from the northern margin show a pronounced oblate fabric (i.e., no extension lineation can be identified within the foliation plane). The oblate fabric can be followed into the marginal area of the biotite granodiorite, though it is less strongly expressed in those rocks more than approximately 1 km from the batholith margin.

At the southern margin of the batholith, thin sections from the so-called Neville pluton and from the hornblende tonalite (*see* Figure 12.1) show a more prolate fabric with a pronounced extension lineation defined by stretched quartz and feldspar crystals. The Neville pluton is interpreted to represent a strongly deformed equivalent of the hornblende tonalite. The fabric in these rocks records flexural slip, on the southern margin of the granitoids, which occurred during D_2 folding of the supracrustal rocks and the hot pluton. Additionally, both the hornblende diorite and the hornblende tonalite show a metamorphic overprint of their fabric (i.e., a change from magmatic to metamorphic textures) throughout the batholith. Apparently, the only heat source for this metamorphic overprint was the intrusion of the later biotite granodiorite. In contrast, except for the marginal areas, the biotite granodiorite shows no high temperature solid-state deformation.

Magnetic Fabric

Measurements of the anisotropy of the magnetic susceptibility (AMS) confirm the stable northwest orientation of the macroscopic foliation (*see* Figures 12.2a and 12.2b). Only in the central part of the southwest lobe, in the hornblende diorite, north-oriented magnetic foliations have been measured (*see* Figure 12.2b). These may represent fabric elements of the earlier, north-oriented folding event.

The magnetic lineations in the Kenogamissi batholith show a stable northwest orientation (plunging to the west), except in the southern part (in the Neville pluton) where the magnetic lineation plunges east (*see* Figure 12.2c). At the western margin in the biotite granodiorite and hornblende tonalite, the magnetic lineations are oriented parallel to the margin.

The volume susceptibilities of the samples vary between the different units. In the hornblende diorite, the volume susceptibilities are in the range of approximately 500×10^{-6} SI. In the hornblende tonalite, the volume susceptibilities of samples are approximately 1000×10^{-6} SI, whereas volume susceptibilities in samples from the biotite granodiorite oscillate at approximately $10\,000\times10^{-6}$ SI. The high volume susceptibilities of the hornblende tonalite and biotite granodiorite indicate a high content of iron-rich minerals in the samples (probably magnetite), which may overwhelm the contributions of paramagnetic minerals to the AMS fabric (e.g., biotite and/or hornblende). Siegesmund and Becker (2000) have shown that, even if the magnetic properties of the samples are dominated by ore minerals, they can still mimic the orientation of the primary ferromagnesian minerals. This observation may apply to the Kenogamissi batholith as well, since the magnetic and macroscopic foliations and lineations are oriented subparallel to each other. Measurements of the ARM (anhysteretic remanent magnetization) will be performed at the University of Ottawa to confirm this relationship between the paramagnetic and ferromagnetic minerals of the batholith.

GEOCHRONOLOGY

Preliminary results of zircon U/Pb age determinations of 2 of the 3 main units of the Kenogamissi batholith are 2686 ± 4 Ma for the hornblende diorite and 2742 ± 2 Ma for the hornblende tonalite. These data are in apparent contradiction with field relationships, observed by the authors and Heather (1993), that indicate the hornblende diorite is crosscut by the hornblende tonalite. Hence, these geochronological data should be considered as preliminary and that the zircons within the hornblende tonalite, used in these preliminary age determinations, may be inherited zircon xenocrysts. Further age determinations using zircons from granitoid samples, collected during the 2001 field season, will be carried out to better constrain the crystallization ages of the different units of the Kenogamissi batholith.

SUMMARY

The observed fabric in the Kenogamissi batholith and the outcrop pattern of the granitoid rocks shows strong evidence for a roughly northwest-directed shortening of the southwestern lobe. The macroscopic, as well as magnetic, foliations are oriented northwest, parallel to the axial surface trace of the Woman River anticline that extends from the greenstone belt into the granitoid rocks. Thin section investigations of samples of the biotite granodiorite show solid-state deformation close to the marginal areas where the foliation (mesoscopic and magnetic) and magnetic lineation are oriented parallel to the batholith margin. The central part of the biotite granodiorite preserves igneous textures that suggest a syn-D_2 emplacement of the biotite granodiorite.

The hornblende tonalite and hornblende diorite units typically show a strong solid-state fabric, especially at the northern and southern margins of the batholith. A strong oblate fabric was recognized in thin sections of the hornblende diorite from the northern margin. This fabric probably developed due to flattening at the northern margin during D_2. Samples from the hornblende tonalite and the Neville pluton at the southern margin of the batholith show a more prolate fabric pointing to flexural shear along the southern limb of the folded batholith. This seems to be confirmed by the orientation of the magnetic lineation in that area (*see* Figure 12.2). Shear fabrics, observed in thin sections, indicate a greenstone-side-up shearing during the development of high-temperature fabrics within the southern margin of the batholith.

Fabrics that can be related to the D_1 folding event are preserved in the core of the folded batholith within the hornblende diorite. Magnetic measurements show a north to south oriented magnetic foliation in this unit (*see* Figure 12.2). The development of this fabric must be ascribed to shortening during D_1.

Whereas the biotite granodiorite, the youngest unit in the Kenogamissi batholith, may have a thin sheet-like shape in three dimensions, the overall shape of the hornblende tonalite and the hornblende diorite can not yet be completely verified. These two units may have intruded as sheets or may represent two different, but not necessarily independent, diapiric bodies. Gravity data collected during the 2001 field season will be used to model a north to south profile across the study area in order to better constrain the three-dimensional shape of the batholith. With this information, it will be possible to identify possible emplacement mechanisms of the hornblende diorite and tonalite and to verify the interpreted sheet-like shape of the biotite granodiorite.

REMAINING WORK

During the winter of 2001 to 2002, the following work is scheduled:

1. prepare the new samples and measure the anisotropy of magnetic susceptibility (AMS)
2. prepare and analyze thin sections (cut according to the macroscopic fabric in three perpendicular directions)
3. complete a detailed study of geochemistry from 20 samples taken from a north-trending profile in the southwestern lobe of the Kenogamissi batholith
4. update the maps to include the new data
5. prepare ArcView® files of the data to include into the OGS database (sample localities, measurement values, etc.)
6. process the collected gravity data

7. geochronology on additional samples, which have been collected to better constrain the age relationship of the different units
8. measure the anhysteretic remanent magnetization (ARM) of selected samples

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13. Project Unit 99-021. Physical Volcanology of Komatiites in the Abitibi Greenstone Belt

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INTRODUCTION

Komatiites are ultramafic volcanic rocks with greater than 18% MgO (Arndt and Nisbet 1982). Since the recognition of komatiites as lavas by Viljoen and Viljoen (1969), it has been appreciated that komatiites must have had unusual physical properties, including very high liquidus temperatures (up to 1640°C), very low dynamic viscosities (down to 0.1 $Pa \cdot s^{-1}$), very high specific heats (up to 1760 $J \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$), and a very large range between the liquidus and solidus (up to 400°C), which permitted them to form very mobile flows with the potential to flow long distances and to crystallize large amounts of olivine before solidifying (see reviews by Nisbet 1982; Huppert and Sparks 1985; Lesher 1989; Williams, Kerr and Lesher 1998). Much work has subsequently been done on their physical properties, phase equilibria and crystallization, geochemistry, and textural variability. However, because there have been no historic komatiite eruptions and because the Archean and Proterozoic volcanic belts in which most komatiites are preserved are folded and faulted, interpretations of their volcanology have been limited to relatively small scales (e.g., Pyke, Naldrett and Eckstrand 1973; Arndt, Francis and Hynes 1979; Lesher, Arndt and Groves 1984; Hill et al. 1990; Cas, Self and Beresford 1999). Because of variations in discharge rate, topography, temperature, volatile content, and viscosity, not all facies will be present in the same area, which further hampers correlations between different areas within the same komatiite flow field. Models have been developed on the scale of entire volcanic successions based on observed stratigraphic relationships (Lesher 1989) or on the scale of entire flow fields based on models developed for Hawaiian basalts (e.g., Hill et al. 1990, 1995). However, basalts had much lower eruption temperatures, much higher viscosities, much narrower crystallization intervals, and much lower heat contents, and those in Hawaii erupted subaerially onto greater slopes, so they are not good analogues for komatiites. Subaqueous flood basalts would be better analogues, at least for thicker, more channellized komatiite flows, but their volcanology is even less well constrained. Nevertheless, the determination of volcanic facies is particularly important as it facilitates recognition of favourable volcanic sequences that may host magmatic nickel-copper-platinum group elements (PGE) sulphide mineralization (Lesher 1989; Barnes et al. 1999).

This project is part of a PhD study based at Laurentian University and the University of Ottawa, under the supervision of Drs. Michael Lesher and Anthony Fowler. The principal aims of the project are to establish variations in volcanic facies of komatiites in the Abitibi greenstone belt (AGB), to test and refine current stratigraphic, tectonic, and metallogenic models for the AGB (Jackson and Fyon 1991; Jackson, Fyon and Corfu 1994; Heather 1998; Ayer et al. 1997, 1999a, 1999b), and to help constrain the volcanic architecture of komatiite flow fields. The AGB was selected for study because of the excellent mineralogical and textural preservation of the rocks, the abundance of glacially polished outcrops, and the excellent geological, geochemical, and geochronological database. A better understanding of the volcanic architecture of komatiites will help constrain stratigraphic, tectonic, and metallogenic models throughout the AGB and may aid in the development of similar models in other greenstone belts. Three broad topics have been addressed thus far: 1) classification of komatiite lava flow facies; 2) determination of regional facies variations of komatiites in the AGB; and 3) determination of local facies variations of komatiites in the AGB. A komatiite lava flow classification has been developed to provide an internally consistent framework for the classification of komatiites in the AGB. Regional facies variations of komatiites in the AGB have been studied by compiling data from both the literature and from previous projects by Drs. Lesher and Fowler, supplemented by field work in critical areas. Local facies variations of komatiites have been studied by detailed mapping of key areas with unparalleled exposure. This multi-scale, integrated approach has been critical in constraining the interpretation of komatiite facies to aid in the interpretation of the volcanic architecture of komatiite flow fields.

PHYSICAL VOLCANOLOGY

Komatiite Lava Flow Classification

Previous volcanological classifications of komatiites have included *textural facies* (e.g., Pyke, Naldrett and Eckstrand 1973; Donaldson 1982), *morphological facies* (e.g., Arndt, Francis and Hynes 1979; Imreh 1980), *flow facies*, and *volcanic facies* (e.g., Lesher, Arndt and Groves 1984; Lesher 1989; Hill et al. 1995; Barnes et al. 1999). Because komatiites exhibit such a wide range of textural, morphological, flow, and volcanic facies, we have utilized a hierarchical method to classify komatiite facies in which the order of classification is from small- to large-scale observations.

Komatiite *textural facies* occur on the scale of individual flow profiles and vary with lava composition, temperature, viscosity, flow rate, cooling, nucleation, and crystallization rates (e.g., Donaldson 1982), forming an extremely wide range of textures including adcumulate, mesocumulate, orthocumulate, porphyritic, platy spinifex, acicular spinifex, aphyric, and autoclastic textures. Textural facies of komatiites are controlled primarily by the eruption rate, cooling rate, degree of olivine accumulation, degree of differentiation, degree of inflation, and timing of ponding.

Komatiite *morphological facies* occur on the scale of individual flow units and vary within and between flow fields depending on eruption rate and style, mode and environment of emplacement, lava viscosity, flow rate, and flow regime, resulting in channels, sheets, lobate sheets, flattened pillows, spherical pillows, autoclastic lavas, and pyroclastic units. Each morphological facies is distinguished by a width:height aspect ratio (Figure 13.1). Sheet flows (high aspect ratio) are a common morphological facies in Archean komatiites. Pillowed flows (spherical or flattened with low aspect ratio) are less common in komatiites than in basalts, although lobate flows (intermediate aspect ratio) are common and perhaps broadly equivalent, reflecting the higher flow rates and lower viscosities of komatiites. Autoclastic rocks, formed by quench fragmentation at the contact of hot lava and cold water, occur along the upper margins of some subaqueous komatiite flows, but thick autoclastic flows are much rarer in komatiites than in basalts, also reflecting the higher flow rates and lower viscosity of komatiites. Pyroclastic komatiites are relatively rare in most areas, probably reflecting their low volatile contents (a consequence of high degrees of partial melting of depleted mantle with no evidence of any metasomatic component in most cases), and deeper water emplacement for most komatiites.

Komatiite *flow facies* include simple and compound flows and volcaniclastic deposits. Simple flows comprise single cooling units, defined by chilled margins in contact with substrate or aqueous environment, whereas compound flows comprise multiple cooling units, commonly resulting from "piling up" of individual flow units (e.g., Walker 1972). An outstanding problem is whether the thin differentiated (spinifex- and cumulate-textured) lobate sheets that are so common in many komatiite

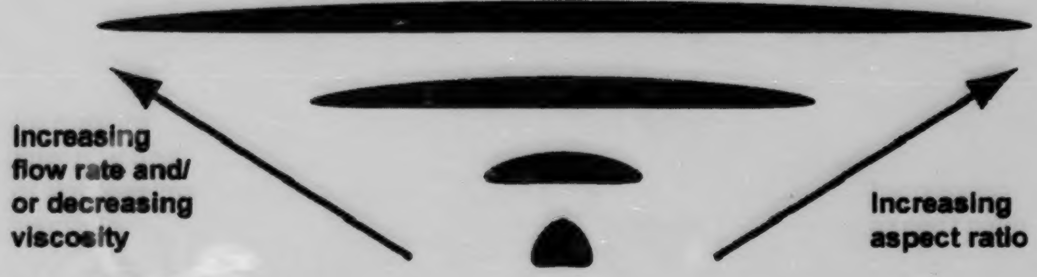

Figure 13.1. Classification scheme for morphological facies based on width:height (W:H) aspect ratio: A, spherical pillow (<2:1); B, flattened pillow (2:1–5:1); C, lobate sheet (5:1–20:1); and D, sheet (>20:1).

sequences are simple or compound flows. Volcaniclastic deposits may produced by quench fragmentation (autoclastic), explosive eruption (pyroclastic), or redeposition (epiclastic).

Komatiite *volcanic facies*, established by stratigraphic mapping in smaller scale areas (e.g., Lesher, Arndt and Groves 1984) and by inference on a larger scale (e.g., Lesher 1989; Hill et al. 1990, 1995; Barnes et al. 1999), include vent pyroclastic facies, sheet flow facies, lava channel facies with or without overbank facies, lava pond facies, lobate sheet facies, and distal pyroclastic and/or epiclastic facies. The basal flows in many komatiite sequences are commonly thicker and are often separated by interflow sediments, whereas the flows in the upper parts are commonly thinner and devoid of sediments (Lesher, Arndt and Groves 1984) indicating that the initial eruptions were more voluminous and more episodic, that later eruptions were less voluminous and more continuous, and that the lava facies regressed over time (Lesher 1989).

A classification scheme has been developed that focusses on the relationship between three major processes to generate a wide range of facies as function of olivine accumulation, differentiation, and aspect ratio provide the most systematic and useful basis for mapping and classifying komatiites (Figure 13.2).

However, it is important to appreciate that the axes in this classification scheme indirectly include many other factors that are important to the physical volcanology of komatiitic rocks. For example, the olivine accumulation axis reflects the amount of magma that can be moved in the pathway (i.e., level of replenishment). The differentiation axis reflects the crystallization rate and timing of lava ponding during emplacement. The aspect ratio axis varies within and between flow fields depending on eruption rate and style, mode (laminar versus turbulent) and environment of emplacement, lava viscosity, and flow regime.

This hierarchical komatiite lava flow classification scheme allows us to establish the relationship between textural and morphological facies that define flow facies and volcanic facies. Komatiite volcanic facies are assumed to vary on the scale of an entire flow field and on the scale of individual flow units, and to have included vent pyroclastic facies, sheet flow facies, lava channel facies with or without overbank facies, lava pond facies, lobate sheet facies, and distal pyroclastic and/or epiclastic facies. However, because no komatiite flow fields have been mapped and because the individual volcanic facies in the parts of flow fields that have been mapped may extend for distances of up to 100 km or more (Lesher, Arndt and Groves 1984; Hill et al. 1995), the proportions of these facies and their spatial configurations are unknown.

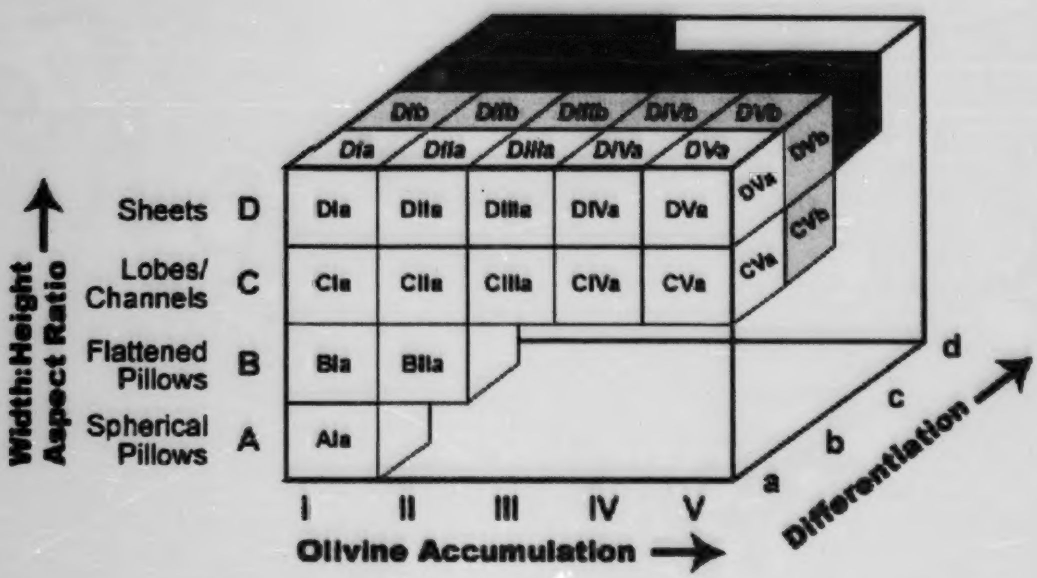

Figure 13.2. 3D facies classification scheme based on degree of olivine accumulation (horizontal axis), morphology (vertical axis), and degree of differentiation (depth axis). Examples of facies types in komatiites and komatiitic basalts include: undifferentiated, aphyric pillowed flows (**AIa**); undifferentiated, aphyric lobate flows (**CIa**); weakly differentiated, non-cumulate lobate flows (**CIb**); moderately differentiated, non-cumulate lobate flows (**CIc**); strongly differentiated, non-cumulate lobate flows (**CId**); moderately differentiated olivine-phyric lobate flows (**CIIc**); moderately differentiated olivine orthocumulate lava channels (**CIIIc**); moderately differentiated olivine mesocumulate lava channels (**CIVc**); moderately differentiated, olivine mesocumulate sheet flows (**DIVc**); and weakly differentiated, olivine adcumulate sheet flows (**DVb**).

REGIONAL FACIES VARIATIONS OF KOMATIITES IN THE ABITIBI GREENSTONE BELT

The Abitibi greenstone belt (AGB) is located in the Superior Province, the largest Archean craton in the world. It is characterized by a high ratio of supracrustal to intrusive rocks and generally low metamorphic grades: predominantly lower greenschist and local prehnite-pumpellyite facies with amphibolite facies occurring adjacent to large granitic plutons (Jolly 1982). It also contains world-class orogenic lode gold deposits, world-class volcanic-associated copper-zinc(-lead) massive sulphide deposits, and minor magmatic nickel-copper (-PGE) and PGE(-copper) deposits (Jackson and Fyon 1991). The AGB has been divided in 2 volcanic zones: the "Northern Volcanic Zone" (NVZ) and the "Southern Volcanic Zone" (SVZ) (Dimroth et al. 1982; Ludden, Hubert and Gariépy 1986; Chown et al. 1992). Felsic, intermediate, and mafic volcanic rocks occur in both zones, but picrites, komatiitic basalts, and komatiites occur predominantly in the SVZ.

Previous work demonstrated that the AGB is composed of a large number of lithologically and tectonically different assemblages (Jackson and Fyon 1991). However, Ayer et al. (1997, 1999a, 1999b) have subdivided the AGB in Ontario into 9 stratigraphically distinct assemblages, 7 of which are dominantly volcanic and 2 of which are dominantly sedimentary. Only 4 of the assemblages contain ultramafic rocks: the Pacaud assemblage (PCA), the Stoughton–Roquemaure assemblage (SRA), the Kidd–Munro assemblage (KMA), and the Tisdale assemblage (TSA). The komatiitic rocks represent only a minor proportion of each assemblage (Ayer et al., in press): the PCA contains less than 1% (by volume)

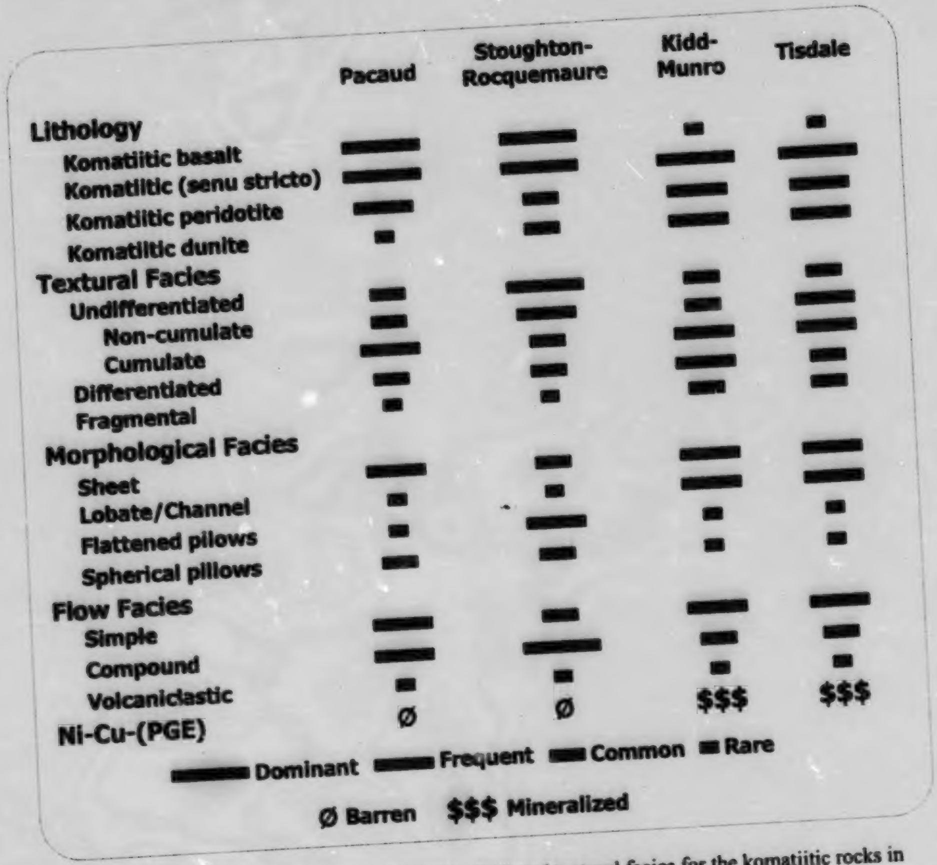

Figure 13.3. Summary of geochemical (or lithological) and textural facies for the komatiitic rocks in different assemblages of the Abitibi greenstone belt.

komatiitic rocks, which occur primarily in the upper part of the volcanic sequence associated with more abundant massive to pillowed tholeiitic basalts; the SRA assemblage contains approximately 2% komatiitic rocks, which generally occur near the base of the assemblage associated with more abundant mafic volcanic rocks; and the KMA and TSA contain approximately 5% komatiitic rocks, which occur near the base of volcanic sequences overlying intermediate to felsic volcanic rocks and underlying mafic volcanic rocks. A second sequence of komatiitic rocks may be present near the top of the Tisdale assemblage, however, they could be a structural repetition of a lower sequence (J.A. Ayer, OGS, personal communication, 2001).

Interpreting volcanic environments is difficult as the environments may be complicated by primary factors (e.g., more than one eruptive centre in each assemblage, differences in eruption rate and style, mode and environment of emplacement) and secondary factors (e.g., metamorphism, alteration, structural complexity). However, there are clear lithological, geochemical, textural, and volcanological differences between the komatiitic rocks in the different assemblages of the AGB. Lithological, textural, and volcanological differences are summarized in Figure 13.3; geochemical differences are summarized in Sproule et al. (in press).

The PCA is dominated by simple flows with lesser compound flows. The simple flows include abundant differentiated flows (ortho- to mesocumulate lower zones and poorly developed spinifex-textured upper zones) and less abundant massive flows (olivine-phyric or ortho- to mesocumulate). The

SRA is dominated by compound flows with lesser simple flows. Massive flows are frequently associated with compound flows, whereas differentiated flows only occur in specific parts of the SRA. The TSA and KMA contain more simple flows than compound flows. Both massive and differentiated flows are frequently present in these assemblages, however, the massive flows are characterized by abundant ortho- to adcumulate lithologies with fewer olivine-phyric lithologies and differentiated flows are characterized by thick orthocumulate lower zones with thin spinifex-textured upper zones.

Volcaniclastic komatiitic rocks occur in the KMA and TSA, and are typically autoclastic (i.e., flow top breccia hyaloclastite or reworked hyaloclastite rather than pyroclastic rock). Only the KMA and TSA contain a large proportion of komatiitic peridotite and komatiitic dunite in massive cumulate lithologies, which are interpreted to represent lava channels or the channel-flow facies of channellized sheet flows and high-level sills. These environments are important, as they are the favoured facies to host nickel-copper (-PGE) mineralization (Lesher 1989). This is consistent with the presence of komatiite-hosted nickel-copper (-PGE) deposits only within the KMA (e.g., Marbridge, Alexo, and Dundonald) and TSA (e.g., Texmont, Redstone, Hart, and Langmuir deposits).

LOCAL FACIES VARIATIONS OF KOMATIITES IN THE ABITIBI GREENSTONE BELT

Kidd–Munro Trend

The Kidd–Munro trend is a belt of tholeiitic and komatiitic, felsic to ultramafic volcanic and associated intrusive rocks (representing the majority of the KMA) that trends east-northeast over a distance of 80 km on the north side of the Destor–Porcupine fault. The komatiites in the belt have been subdivided into three areas: 1) eastern Kidd–Munro area (Munro, McCool and Warden townships); 2) central Kidd–Munro area (Clergue, Dundonald and Stock townships), and 3) western Kidd–Munro area (southwestern Little, southwestern Tully, Prosser, Wark, Carnegie and Kidd townships). This is the same subdivision used in our complementary study on the geochemistry of komatiites in the AGB (Sproule et al. in preparation).

EASTERN KIDD–MUNRO AREA

The eastern Kidd–Munro area includes Munro, McCool and Warden townships, but our field work thus far has focussed on the area of the Potter Mine in Munro Township, which contains abundant komatiitic, lesser mafic, and rare felsic volcanic rocks. Minor nickel-copper (-PGE) mineralization occurs at the Mickel showing in Dee's Flow in the southern part of Munro Township (Davis 1997; Davis and Shore 1999) and significant volcanic-associated massive copper-zinc(-lead) mineralization occurs at the Potter and Potter–Doal mines in the north-central part of Munro Township. The Potter Mine area is bordered by the McCool Hill syncline to the north, the Centre Hill fault to the south, and the mafic-ultramafic Centre Hill complex to the east. The Potter Mine volcanic succession may be subdivided into 3 lithostratigraphic sequences including 1) a lower komatiitic sequence; 2) a middle tholeiitic basalt hyaloclastite sequence with co-magmatic peperitic basalt sills, argillaceous sediments, and komatiites; and 3) an upper komatiitic sequence (Gamble and Gibson 2000). "Lava lake" (Arndt 1986) and Pyke Hill (Pyke et al. 1973) occur in the upper komatiitic sequence. The metamorphic grade in Munro Township is very low (prehnite-pumpellyite to lower greenschist facies) with excellent preservation of original igneous textures and geological relationships.

Pyke Hill (Munro Township)

Pyke Hill is located in the northeastern part of Munro Township, approximately 1 km ESE of the Potter Mine, and represents one of the best preserved and best exposed sequences of thin differentiated (spinifex-textured) and massive komatiite flows in the world. It is being studied to determine whether it represents a series of simple flows or a number of compound flows. At least 60 flows have been identified over an exposure width of approximately 125 m (Pyke et al. 1973). Individual flows range in thickness from 0.5 to 15 m, averaging approximately 3 m (Pyke et al. 1973). The relative proportions of spinifex-textured "A" zones and cumulate-textured "B" zones vary within individual flows, owing to irregularities along the contact between the zones in response to different rates of cooling. The ratio averages approximately 2:1 at both Pyke Hill (Pyke et al. 1973) and Spinifex Ridge in Quebec (Mueller et al. 1999), confirming that these areas contain primarily non-cumulate rather than cumulate flows. However, preliminary data indicate that the proportion of A:B zones decreases with increasing thickness, consistent with increases in flow thickness increasing with the amount of olivine accumulation, a trend also observed in Western Australia (Lesher et al. 1984; Lesher 1989). The southern (stratigraphically lower) part of Pyke Hill is dominated by thin and thick differentiated non-cumulate flows, the central part by thin undifferentiated non-cumulate flows, and the northern (stratigraphically upper) part by thin differentiated non-cumulate flows, indicating that the eruption rates waned and waxed through the sequence. However, well-differentiated flows are interlayered within sequences dominated by poorly differentiated flows, indicating that the timing of ponding varied on a flow-by-flow basis. Poorly differentiated, non-cumulate flows, especially those with lobate sheet and flattened-pillow forms (rather than sheet flows) are spinifex textured along their margins and along fractures, indicating rapid crystallization due to extensive hydrothermal cooling and thermally constrained crystallization (Shore and Fowler 1999). Flattened pillows contain shelves that were interpreted by Shore (1996) as molten lava breakouts. However, the thicker parts of some lobate flows exhibit incomplete secondary selvages inside the major external selvages, possibly indicating growth occurred by progressive inflation.

Lava Lake (Munro Township)

"Lava lake" (Arndt 1986) is located in the north-central part of Munro Township, immediately west of the Centre Hill complex and approximately 1 km west of Pyke Hill. It is also very well exposed and is being studied as an example of a possible komatiite lava lake. The area is dominated by massive to weakly layered, medium-grained olivine adcumulate and was interpreted by Arndt (1986) to be an approximately 120 m thick lava lake that youngs toward the north. However, recent work by the Hunter Dickenson Group, based on logging and interpretation of new diamond drill cores, suggests that the Centre Hill complex and the komatiitic horizon have both been folded by regional deformation into a west-closing anticline. Our geological mapping and drill core logging, using chilled margin polarities, asymmetric differentiation within flow units, and vesicle orientations, suggest that the "Lava lake" is stratigraphically equivalent to the rocks exposed at Pyke Hill, but that it lies on the southern limb of the anticline and therefore faces south rather than north, and that it may represent a thick series of thick sheet flows or a thin series of thick sheet flows overlain by a thin lava lake additional. Field work is in progress to further test these interpretations.

CENTRAL KIDD–MUNRO AREA

The central Kidd–Munro area includes Clergue, Dundonald and Stock townships, but our work has been focussed on newly stripped exposures around the Alexo Mine (along the boundary of Dundonald and Clergue townships) and Dundonald Beach (southeastern corner of Dundonald Township). The geology of Dundonald Township has been summarized by Davis (1997, and references therein) and is characterized by a major westward-plunging "Z" fold. The rocks in the sequence include abundant intermediate to mafic volcanic rocks, lesser felsic volcanic rocks, a mafic-ultramafic sill (Dundonald Sill), and a regionally extensive komatiitic unit. The komatiitic horizon hosts several nickel-copper (-PGE) deposits, including the Alexo Mine and Kelex zone, Dundeal zone, Dundonald Beach, and Dundonald South.

Alexo Mine (Dundonald Township)

The Alexo Mine area is located on the northeast-dipping central limb of the Dundonald fold structure and is being studied because it could represent one of the best preserved and best exposed mineralized cumulate komatiite lava channels in the world. The stratigraphic succession in this area comprises four sequences of komatiitic rocks intercalated with intermediate volcanic rocks (Davis 1999). The younging indicators in the komatiitic units (e.g., flow-top breccias, asymmetrically zoned spinifex textures, transgressive lower margins of lava channels, disseminated and/or net-textured and/or massive ore segregation profiles) and the andesites (e.g., flow-top breccias, pillows) consistently face northward to eastward, and, because the compositions of the andesites change systematically from more tholeiitic in the south to more calc-alkaline in the north, the sequence is interpreted to represent an intact sequence of intercalated komatiites and andesites (P.C. Davis, MPH Consulting Ltd., personal communication, 2001). This means that the Alexo Mine, the Alexo "small pit", and the Kelex zone all occur within distinct komatiite units (Davis 1999).

The komatiite–andesite contact east and west of the Alexo Mine horizon was stripped by Hucamp Mines Ltd. in 2001, exposing the basal contact of the mineralized lava channel. Because the metamorphic grade in the Alexo area is only lower greenschist facies, these areas provide almost complete exposure of glacially polished outcrops of the well-preserved contact between footwall pillowed, massive, and hyaloclastic andesite and the overlying cumulate komatiite unit. The contact is generally very sharp between the two lithologies and outlines a pronounced topographic depression that clearly transgresses massive andesite and associated hyaloclastite without any evidence for a regolith. The presence of andesitic fragments in the lower part of the komatiite, komatiitic dikes projecting downwards into pillowed andesite, and pervasive contact metamorphic alteration adjacent to the contact indicate that, similar to many other areas where nickel-copper (-PGE) sulphides have formed, lava emplacement was channellized and most likely turbulent (Huppert and Sparks 1985; Williams, Kerr and Lesher 1998), not passive and laminar (cf. Beresford and Cas 2001), and most likely involved thermomechanical erosion (see Lesher, Arndt and Groves 1984; Lesher 1989). Further field work is in progress to completely characterize this exceptionally well-preserved and well-exposed channellized komatiite flow.

Dundonald Beach (Dundonald Township)

The Dundonald Beach is an area of stripped outcrop on the southeast-dipping, southern limb of the Dundonald fold structure. It is being studied because it contains excellent exposures of thin komatiitic basalt flows intruded into graphitic sediments (Davis 1997, 1999) and provides unique insights into the behaviour of invasive komatiite flows that have thus far only been inferred from drill core observations (Gillies 1993, Beresford and Cas 2001). The area exposes a sequence of thin komatiitic basalt flows, intercalated graphitic argillaceous metasedimentary rocks and associated peperites, thick olivine meso- to adcumulate komatiite flows, and thick differentiated olivine cumulate/pyroxene spinifex flows overlying a felsic heterolithic breccia (Davis 1997, 1999). The footwall felsic volcanic rocks contain thin (~10 cm) dikes of spinifex-textured komatiite (Davis 1997). The main exposure was cleared by Falconbridge Ltd. in 1989 and adjacent exposures to the east and south were cleared by Hucamp Mines Ltd. in 2000.

The lower part of the komatiitic sequence is composed of pyroxene spinifex-textured komatiitic basalt flows and very fine-grained, massive komatiitic basalt flows and sills. There are 2 types of intrusive units: 1) relatively thick (~4 m), fine- to medium-grained massive intrusions with thin (~2 to 3 cm), very fine-grained chilled margins; and 2) relatively thin (<50 cm), fine-grained intrusions with very thin (<1 cm), very fine-grained chill margins possessing both globular and irregular textures suggesting contamination by the country rocks. The second type has been injected into previous komatiitic basalt flows, producing thin *en échelon* sills, or into unconsolidated graphitic argillitic sediments, producing both *blocky and fluidal peperites* containing both clasts of sediment within komatiite and clasts of komatiite within sediment. Peperites with the clasts of komatiite surrounded by sediment occur on larger scales (metres) than the peperites with the clasts of sediments surrounded by komatiites(centimetres). Both textures generally occur close to each other: along the margins of the intrusions; or they form distinctive globular textures within the intrusions, where they form distinctive "egg-shell breccia" textures (Davis 1997, 1999). Thus, this area provides considerable insights into the mechanisms of komatiite intrusion into unconsolidated sediments. Additional field work is currently underway in this area to characterize the nature of lava emplacement.

Shaw Dome

The Shaw Dome area is located approximately 20 km southeast of Timmins and is composed primarily of volcanic rocks with minor felsic intrusive rocks (Pyke 1978, 1982). Although the komatiites in this area are more deformed, more altered (local talc-carbonate alteration), and metamorphosed to lower greenschist facies (Larson 1996), geological relationships and relict igneous textures are locally well preserved in stripped outcrops that expose transgressive contacts between thick, weakly differentiated cumulate flows.

The Shaw Dome is cored by calc-alkaline mafic and felsic volcanic rocks, intruded in the upper parts by differentiated mafic to ultramafic sills, and is overlain by tholeiitic basalts intercalated with komatiites, komatiitic basalts, and minor sulphide-facies iron formation. These komatiites are correlated with the Tisdale assemblage (Ayer et al. 1999b). They have been described by Larson (1996) and Baird (1999) and are the main hosts to the nickel-copper (-PGE) deposits in the area (e.g., Langmuir 1 and 2, McWatters, Hart, Redstone and Galata) (Coad 1979; Green and Naldrett 1981).

REDSTONE PAVEMENT

One of the best exposures of the komatiites occurs in a stripped outcrop approximately 1 km south of the Redstone Mine site in the western part of Eldorado Township. Three flows are exposed in the outcrop, but only the middle flow has its lower and upper contacts exposed. All three flows have relatively thick (~20 m) lower cumulate "B" zones, which are locally intensely polysutured, but are composed mainly of texturally well-preserved meso- to orthocumulate komatiite containing serpentine pseudomorphs after medium-grained (1 to 2 mm) euhedral olivine. The two flows with exposed upper contacts have relatively thin (~4 m) upper "A" zones composed of very coarse-grained olivine crescumulate komatiite and coarse- to medium-grained random olivine spinifex-textured komatiite, but no fine-grained random spinifex-textured komatiite or flow-top breccia. Thus, these are cumulate flows, intermediate in terms of degree of olivine accumulation between thin non-cumulate Pyke Hill-type flows and the thick cumulate flows that host the majority of the nickel-copper (-PGE) mineralization in the Shaw Dome (e.g., Green and Naldrett 1981) and elsewhere (Lesher 1989). The contacts with overlying flows are very sharp and wavy (contact between Flow 1 and Flow 2) or very sharp and jigsaw-textured with small dikes of fine-grained komatiite injected into the overlying cumulate rock (contact between Flow 2 and Flow 3). The cumulate zones of the lower two flows contain small (average size 5 cm) subrounded pods of fine- to medium-grained olivine spinifex-textured rock with very sharp margins that may represent pockets of trapped liquid or xenoliths. They are common in the lower parts of the cumulate zones and are absent in the upper parts of the cumulate zones, supporting the latter interpretation and suggesting that they have been derived by mechanical erosion of the upper spinifex-textured parts of the underlying flows. The jigsaw-shaped, locally intrusive contact between flows 2 and 3 is interpreted to represent compaction of the underlying partially molten spinifex-textured zone by the overlying cumulate zone after mechanical erosion of the upper spinifex-textured parts of the underlying flows. This explains the presence of spinifex xenoliths. Thus, this outcrop provides considerable insights into the processes of thermomechanical erosion in komatiites, especially in flows that are intermediate in terms of thickness and degree of olivine accumulation between classic Pyke Hill-type (thin, non-cumulate) flows and Kambalda-type (thick, cumulate) flows. Petrographic work is being be done to further clarify the nature of the contacts in this area.

Bartlett Dome

The Bartlett Dome is located approximately 40 km south of Timmins and is interpreted to be stratigraphically equivalent to and contiguous with the Shaw Dome to the north (Jensen 1985). It is composed of supracrustal metavolcanic and metasedimentary rocks intruded by very large batholiths of felsic intrusive rocks (e.g., Adams Pluton, Geikie Pluton, and the Peterlong Lake Complex). The volcanic sequence is composed of a lower sequence of intermediate to mafic volcanic rocks, a central sequence of komatiitic rocks that is laterally most extensive and best exposed in McArthur and Geikie townships, and an upper sequence of mafic volcanic rocks. Some of the best exposures occur in the Serpentine Mountain area, which is probably the stratigraphic equivalent of the komatiites at the Texmont Mine, which was exploited in the 1970s (e.g., Atkinson 1999). The metamorphic grade in the Bartlett Dome is relatively low (mainly greenschist facies) with locally good preservation of original igneous textures and geological relationships, but the rocks are locally sheared and altered to talc-carbonate assemblages.

SERPENTINE MOUNTAIN

The komatiitic rocks at Serpentine Mountain are located between the gravel road and the power line near the Mountjoy River in central McArthur Township. An outcrop close to the road has been described by Atkinson (1999) and is characterized by abundant spinifex-textured komatiite dikes within a sequence composed primarily of massive komatiites and one well-differentiated flow (including a well-defined B1 horizon). An outcrop under the power line is composed of fine-grained random olivine spinifex-textured komatiite containing small (20 to 30 cm) spherical to ellipsoidal fragments of medium-grained olivine cumulate rock with polysutured joints. There are 2 possible interpretations of this outcrop: 1) it may represent a spinifex-textured dike, similar to that exposed near the road, that has ripped up and partially assimilated cumulate komatiite wall rocks, or 2) it may represent a spinifex-textured flow exhibiting a relationship the reverse of that observed at the Redstone pavement (*see* "Shaw Dome"). However, the latter interpretation would require erosion of the entire spinifex-textured upper zone and part or all of the underlying cumulate zone of an unexposed underlying flow, entrainment of the cumulate rock fragments, and preservation in the upper spinifex-textured zone, which seems unlikely. More work is being done to aid in the interpretation of these exposures.

Halliday Dome

The Halliday Dome area is located approximately 80 km south of Timmins. It represents a major antiformal structure that trends eastward from Sothman Township across Halliday Township into Midlothian Township before disappearing beneath Proterozoic sediments. The dome is cored by massive or pillowed intermediate volcanic and fragmental felsic volcanic rocks overlain by an extensive komatiitic horizon that can be traced over 40 km (Mullen 1983). A few pods of ultramafic rock have been found in the core of the Halliday Dome, which may represent sills analogous to those in the Shaw Dome (*see* "Shaw Dome"). The metamorphic grade in the Halliday Dome is relatively low (mainly lower greenschist facies) with good preservation of original igneous textures and geological relationships.

SOTHMAN DEPOSIT (SOTHMAN TOWNSHIP)

The Sothman nickel-copper (-PGE) deposit occurs along the south-southwestern-dipping, southwestern limb of the Halliday Dome, along the southern border Sothman Township, approximately 30 km east of Highway 144. It is hosted by a thick ultramafic body with a dunite core and peridotite margins that has been previously interpreted to be a sill intruded into intermediate volcanic rocks (e.g., Watkins 1972), but is most likely a lava channel. An area along the basal contact of the body was stripped in 2000 by Hucamp Mines Ltd., providing near complete exposure of glacially polished outcrops of the embayed contact between footwall massive andesite and the overlying cumulate komatiite unit.

Field work done in this area during Summer 2001 did not reveal any evidence for an extrusive or intrusive origin for this ultramafic body, as the stripped area exposes only the basal part and not the upper part which might exhibit extrusive (e.g., flow-top breccia and upper spinifex-textured zone, conformable unmetamorphosed hanging-wall rocks) or intrusive (e.g., contact metamorphosed hanging-wall rocks, discordant contacts) features. Nevertheless, this environment clearly represents a channellized flow or channellized sill where magma flow was focussed within a topographic and/or thermomechanically produced embayment similar to those observed at Alexo. The underlying andesites exhibit patchy alteration and silica veining within 30 cm of the contact with overlying olivine pyroxenite, which are most pervasive at the base of the channel, suggesting that they represent a contact metamorphic feature. Thin (~10 to 50 cm) felsic dikes, which crosscut the komatiitic unit at a high angle and terminate at the basal contact, may represent partial melts of the andesite produced during thermal erosion of the environment (P.C. Davis, MPH Consulting Ltd., personal communication, 2001).

The mineralization occurs approximately 0.8 m above the basal contact within olivine pyroxenite and is composed of interlayered net-textured sulphides, disseminated sulphides, and barren olivine pyroxenite. However, disseminated mineralization always overlies net-textured mineralization, suggesting that the sequence youngs toward the south, consistent with the regional geology. The presence of barren komatiitic cumulate rocks within the main mineralized horizon and the apparent disruption of mineralized zones by olivine pyroxenites suggest that the environment was quite dynamic and was characterized by successive replenishment of magma and sulphides into the channel. Additional mapping is planned to constrain the origin and dynamics of this channellized environment.

Round Lake Dome

The Round Lake Dome area occurs approximately 15 km south of Kirkland Lake. It is defined by a large felsic intrusive body, the Round Lake batholith, which is bordered on the north, east, and south by mafic and ultramafic metavolcanic rocks of the Stoughton–Rocquemaure and Tisdale assemblages. The komatiitic rocks in the Stoughton–Rocquemaure assemblage are underlain and overlain by mafic and lesser intermediate volcanic rocks (Ayer and Trowell 2000). The metavolcanic rocks are penetratively deformed along the margins of the batholith and within faults and shear zones, but are much less deformed away from the batholith (Jackson 1994). The metamorphic grade in the komatiitic rocks around the Round Lake Dome is higher than in many other areas of the Abitibi greenstone belt (lower greenschist to locally lower amphibolite facies), but there is good preservation of original igneous textures and geological relationships in many areas.

BOSTON CREEK UNIT (BOSTON TOWNSHIP)

The Boston Creek unit and Misema komatiite occur on the eastern side of the Round Lake Dome and are the most extensive ultramafic units in the Abitibi Greenstone Belt. They define an arc-shaped pattern around the eastern margin of the Round Lake Dome, trending broadly north for more than 30 km. Thus far, only the Boston Creek unit has been studied as part of this project.

The Boston Creek unit is best known because it appears to be derived from a ferropicritic magma (Stone, Jensen and Church 1987). It is approximately 100 m thick and exhibits the following internal differentiation, from base to top (Stone, Jensen and Church 1987): a thin basal pyroxenite (~3.5 m), olivine cumulate (~30 m), pyroxene cumulate (~9 m), gabbro (~15 m), parallel-oriented acicular pyroxene spinifex (~30 m), randomly oriented pyroxene spinifex (~0.30 m), and a very thin fine-grained upper chill margin (~1 to 2 cm). The peridotite zone appears to be laterally restricted and is interpreted as channellized environment (Stone et al. 1996). Although no flow-top breccia has been identified, the Boston Creek unit has been interpreted to be extrusive on the basis of the presence of spinifex textures and the presence of vesicles in the upper chilled margin (Stone et al. 1995). However, spinifex textures only indicate rapid crystallization of an ultramafic liquid and also form in veins (see above) and vesicles only indicate exsolution of volatiles and also form in shallow intrusions. In order to further investigate the environment of emplacement of the Boston Creek unit, it has been studied in 2 sections near O'Donald Lake in the southeastern part of Boston Township, approximately 2 km from the old shaft of the mine. Particular attention was focussed on the upper contacts between the Boston Creek unit and overlying volcanic rocks.

Section A

The upper contact of the Boston Creek unit along section 2 of Stone et al. (1996) is sheared, but well exposed. The upper random pyroxene spinifex-textured zone grades very rapidly over a distance of 20 to 30 cm into a very thin fine-grained, locally vesicular random spinifex-textured upper margin. No aphanitic rocks or autoclastic breccias similar to those preserved at the tops of most komatiite flows are present. The rocks above the contact are sheared "intermediate" volcanic rocks containing discontinuous bands of quartz. The overlying "intermediate" volcanic rocks do not show any mesoscopic evidence of contact metamorphism, but they may represent contact metamorphosed mafic volcanic rocks, so work is in progress to constrain the nature of the rocks more distant from to the contact.

Section B

The upper contact of the Boston Creek unit along section 1 of Stone et al. (1996) is very similar to the that described above, except that the contact is not sheared and it shows evidence suggestive of an intrusive origin for the Boston Creek unit. The upper part of the Boston Creek unit in this area contains clasts of the overlying "intermediate" volcanic rocks and the overlying "intermediate" volcanic rocks contain several thin veins of more mafic material, similar in composition to the Boston Creek unit. The fragments are very fine grained and have altered rims. Petrographic and geochemical work is presently in progress to determine the composition of the fragments and the overlying rocks to help constrain the environment of emplacement of the Boston Creek unit, but, at this stage of interpretation, it seems possible that it is a sill, not a flow.

OTTO LAKE (OTTO TOWNSHIP)

Several excellent outcrops of Tisdale Assemblage komatiites occur on the southwestern shore of Otto Lake, approximately 5 km southeast of Swastika. The outcrops studied expose 3 individual flows, which, from base to top, are a partially exposed differentiated flow (Unit 1), a completely exposed differentiated flow (Unit 2), and a partially exposed pillowed flow (Unit 3). They dip steeply southwest, consistent with the regional geology.

Unit 1

Only the upper, random pyroxene spinifex-textured zone of this flow is exposed in the northeastern part of the main outcrop, but there are smaller peridotite outcrops to the northeast, which are probably part of the same flow. The grain size of the pyroxene spinifex decreases to the northwest, suggesting that the flow youngs in that direction.

Unit 2

This flow is completely exposed in the northeastern part of the outcrop and the upper part is exposed in the southwestern part of the outcrop. It is approximately 12 m thick and is underlain by pyroxene spinifex-textured rocks of Unit 1 and overlain by pillowed komatiitic basalt of Unit 3. It is strongly differentiated, comprising, from base to top, thin lower chilled margin (<5 cm), pyroxene cumulate (~6 m), B1 zone (~15 to 20 cm), parallel pyroxene spinifex, random pyroxene spinifex, random olivine spinifex (total ~5 m), and flow-top breccia (~30 cm). The ratio of A:B zones is approximately 1:1, suggesting that this is a non-cumulate flow. The B zone is polysutured and the A zone contains multiple layers of parallel pyroxene spinifex and random pyroxene spinifex indicating that the cooling and/or nucleation and/or crystallization process in the flow was more complicated than in simple Pyke Hill-type flows.

Unit 3

This flow is composed of pillowed komatiitic basalt. The pillows are slightly elongate in a northeast to southwest orientation and appear to young toward the northwest. The pillows selvages are thin, and discontinuous, but are well defined in the upper part of the flow, but the rocks grade downwards into random olivine spinifex of Unit 2. This suggests that Units 2 and 3 possibly represent a transition between a simple to compound unit, reflecting a change in eruption rate, magma supply, etc. during emplacement. Petrographic and geochemical analysis work is in progress to test this hypothesis.

FUTURE WORK

Additional work is in progress in all of these areas. Some areas, including Redstone, Serpentine Mountain and Otto Lake, require follow-up petrographic and geochemical work. Other areas, including Pyke Hill, Lava lake, Alexo, Dundonald Beach and Boston Creek, require additional field work with follow-up petrographic and appropriate geochemical study. Additional areas will also be studied, including fragmental ultramafic deposits in Halliday Township. Sequence-scale stratigraphic studies are planned at Alexo Mine and in the Potter Mine area. These data will be used to provide constraints on the regional volcanological facies interpretation.

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14. Project Unit 01-44. Geographic Information System (GIS) and Remote Sensing Applications in the Identification of the Location and Spatial Association of Kimberlites in the Lake Timiskaming Structure

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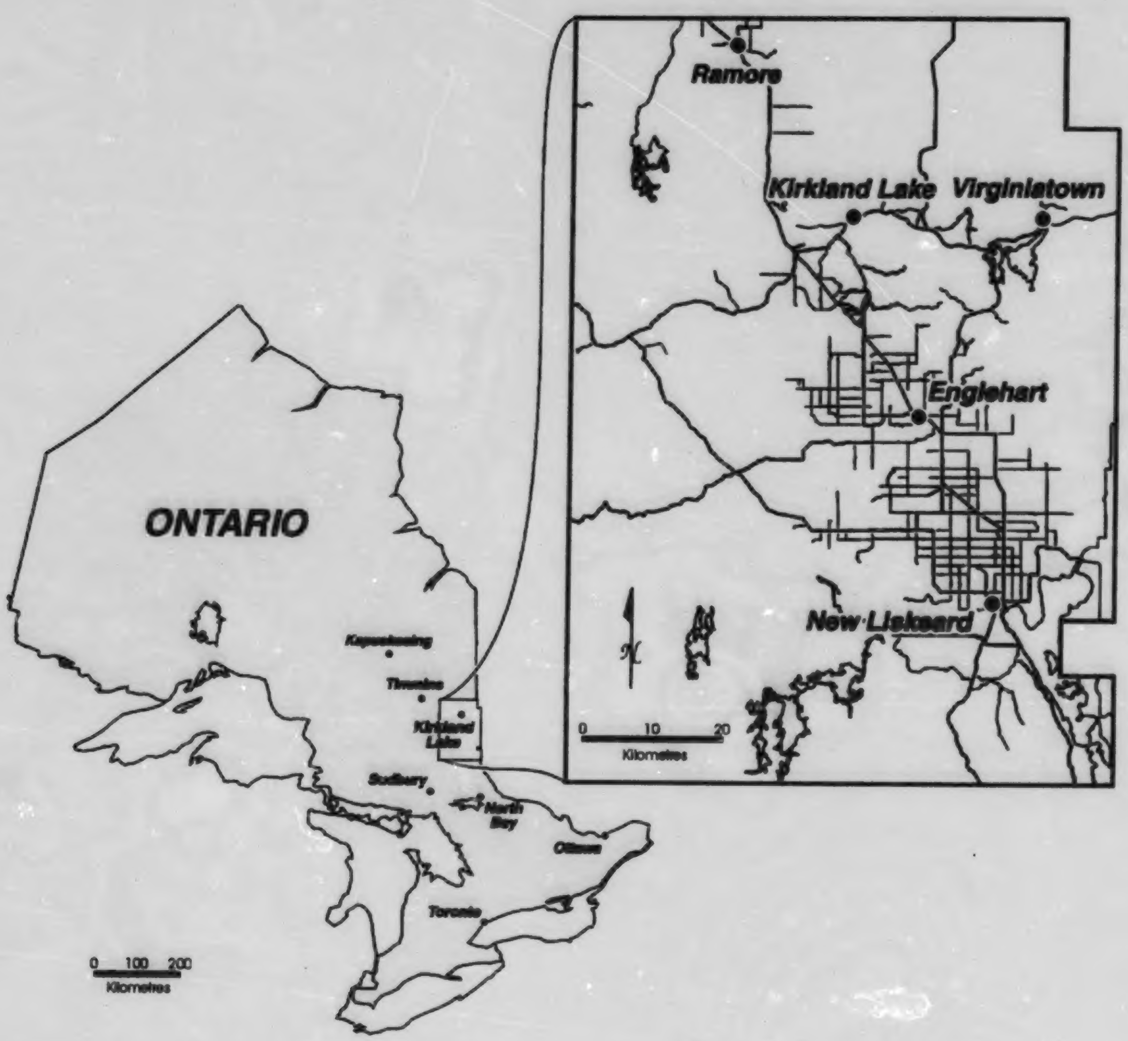
INTRODUCTION

The Canadian Space Agency (CSA) and the National Aeronautics and Space Administration (NASA) created a program to conduct additional research and application development using data from Canada's RADARSAT-1 satellite. This program is referred to as the Application Development and Research Opportunity 2 (ADRO-2). The Ontario Geological Survey, in conjunction with Laurentian University, requested radar data under the ADRO-2 program to study the kimberlites in the Lake Timiskaming structural zone.

The focus of this research is two fold: 1) to characterize the environment around known kimberlites by quantitatively treating standard geological data sets within a geographic information system (GIS); and 2) to determine the additional information, if any, which remotely sensed imagery in the form of Radarsat SAR (Synthetic Aperture Radar) data might contribute to characterizing kimberlites on the landscape. The following describes the work done to date in both approaches.

GENERAL GEOLOGY

Kimberlite pipes are known to occur in the Kirkland Lake–Cobalt and Wawa areas in addition to the region of Attawapiskat in the James Bay Lowlands. However, it is very likely that many more kimberlites have yet to be discovered in Ontario (Sage 1996). Exploration for diamond-bearing kimberlites remains active along the northwest-striking Lake Timiskaming structural zone. Kimberlite pipes are located along the Lake Timiskaming structural zone where the latter is intersected by lineaments, faults, or major lithologic breaks (Sage 2000). Kimberlites commonly occur as clusters of 1 to 20 closely spaced pipes (Mitchell 1986). For a cluster, Mitchell (1986) indicates that the pipes should be closer than 1 km and each cluster separated by distances of 2 km or more. These distances are too restrictive and, if applied to the kimberlites of the Kirkland Lake and Cobalt areas (Figure 14.1), it would generate mostly one-pipe kimberlite clusters (Sage 1996). Currently, there are 2 identified areas of regional clustering centred around Kirkland Lake and New Liskeard–Cobalt within which there are subclusters (Sage 1996). This "apparent" clustering may be, in part, an artifact of mineral exploration and discovery (Sage 1996).


Ramore
Kirkland Lake
Virginiatown
Englehart
New Liskeard
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0 10 20
Kilometres
ONTARIO
Kapuskasing
Timmins
Kirkland Lake
Sudbury
North Bay
Ottawa
Toronto
0 100 200
Kilometres

Figure 14.1. Location of the study area.

APPLICATION OF THE GEOGRAPHIC INFORMATION SYSTEM (GIS)

The basic hypotheses being evaluated and tested during this study are the following: 1) can we identify the structural controls of the localization of the kimberlites in the Lake Timiskaming structural zone?; and 2) can the integration of Radarsat data with other geophysical data sets provide a product that can be used for both bedrock mapping and target identification for mineral exploration?

In response to these hypotheses, the following database was compiled using the ArcView® Geographic Information System. Planimetric information was provided by the Natural Resource Values Inventory System (NRVIS) at a scale of 1:20 000. Quaternary (Barnett, Henry and Babuin 1991)and bedrock geology (Ontario Geological Survey 1991) were obtained from the Geology of Ontario map sets. A digital elevation model (DEM) with a 25 m cell size was provided by the Ontario Ministry of Natural Resources (OMNR). The Abitibi compilation data set (Ayer and Trowell 2000) at a scale of 1:100 000, which includes faults, folds, dikes, contacts, etc., was also added to the database. The geophysical data sets (gravity, magnetic, and conductivity) were converted from image to grid files and incorporated into the database. R.P. Sage of the Ontario Geological Survey (OGS) provided the geographic coordinates for the known kimberlites in the study area.

A K-means clustering analysis was performed on the known kimberlites to statistically determine how many spatial clusters were located in the study area. The K-means clustering routine is a procedure for partitioning all the study sites into "K" groups, in which K is a number assigned by the user (in this case, K was set at 5). The routine finds K seed locations in which the distances between points within clusters are small, but the distances between seed locations are large. If K is small, the clusters will typically cover larger areas. Conversely, if K is large, the individual clusters will typically cover a smaller area (CrimeStat 1999). Two clusters were identified using this technique: the first cluster (Group 1) is composed of 15 kimberlite pipes; while the second cluster (Group 2) includes 3 kimberlite pipes. Figure 14.2 represents the 2 clusters (Groups) found in the study area. In the future, the same algorithm will be run on each of the identified clusters separately, as the sheer distance between them was determined to have biased the analysis.

In examining individual kimberlites or clusters of kimberlites along the trend of the Lake Timiskaming structural zone, Sage (1996) stated that it is probable that the apparent local control is a structurally high-level feature (i.e., fault, shear zone, major lithologic boundary) that permitted easy access of the kimberlite magma into the upper crust and has no direct bearing on the generation of the kimberlite magma or even its movement in the upper mantle or lower crust. Following this logic, the second phase in the research was to calculate the distance for each known kimberlite (18 kimberlites) to the nearest linear feature (i.e., major faults, minor faults, dike, and fold). Once all the individual distances were determined, a mean distance value for each group (Group 1 and 2) was calculated for each linear feature. The mean distances are important in this study because they are used as radii centred on a kimberlite in order to create spatial "masks", which are then employed to extract quantitative information from the geological and geophysical data sets. Table 14.1 contains an example of the data acquired using this technique. Samples of their distribution are shown in Figures 14.3a and 14.3b.

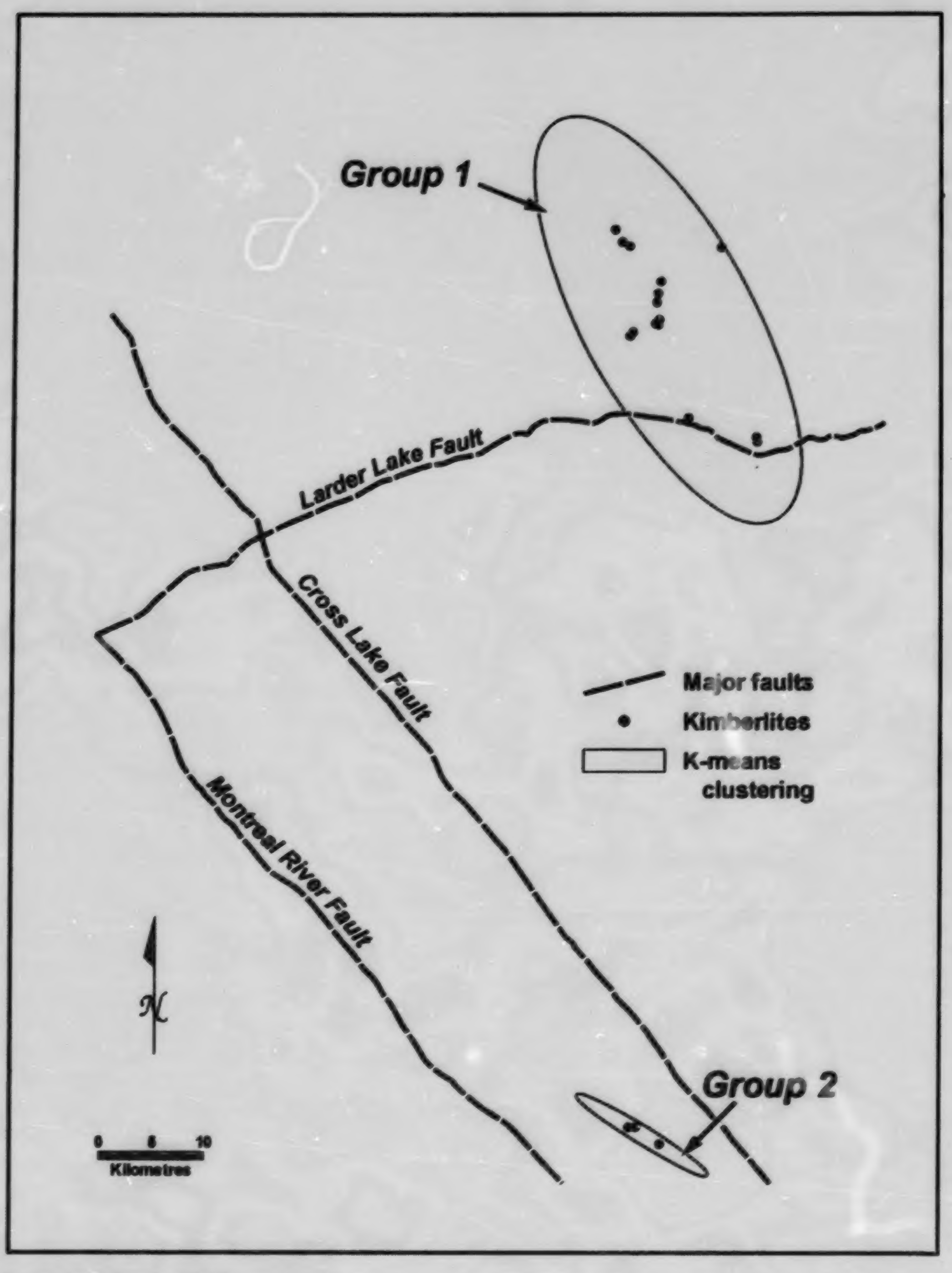
Group 1
Larder Lake Fault
Cross Lake Fault
Montreal River Fault
Major faults
Kimberlites
K-means clustering
N
Group 2
0 5 10
Kilometres

Figure 14.2. Result of the K-means analysis.

Table 14.1. Linear distance (metres) between kimberlites and major faults and kimberlites and minor faults.

ID	Name	Type	UTM East	UTM North	InDMajFalt	MeDMajFalt	InDMinFalt	MeDMinFalt
1	Kimberlite 1	–	579685	5348767	16211.40	9964.55	62.17	973.60
2	Kimberlite 2	–	579017	5350044	17558.20	9964.55	720.58	973.60
3	Kimberlite 3	–	583043	5344037	12038.65	9964.55	2694.01	973.60
4	Kimberlite 4	–	583011	5341042	9039.72	9964.55	656.16	973.60
5	Kimberlite 5	–	580691	5340428	7878.20	9964.55	1206.70	973.60
6	95-1	Blow	580564	5265311	6399.79	5918.55	115.16	546.60
7	95-3(95-2)	Pipe	583440	5263700	5389.56	5918.55	976.67	546.60
8	96-1	Blow	581230	5265320	5966.31	5918.55	547.98	546.60
9	Morisette Creek	Pipe	580475	5339825	7487.69	9964.55	990.81	973.60
10	A-1	Pipe	583300	5344850	13042.55	9964.55	2113.46	973.60
11	AM47	Pipe	582875	5343000	11169.14	9964.55	2144.75	973.60
12	A-4(A)	Pipe	583140	5341300	9517.77	9964.55	830.80	973.60
13	A-4(B)	Pipe	582820	5340900	9085.68	9964.55	857.03	973.60
14	Diamond Lake #1	Pipe	592350	5330200	1599.13	9964.55	264.70	973.60
15	Diamond Lake #2	Pipe	592450	5329775	1270.51	9964.55	688.92	973.60
16	Upper Canada Mine	Dike	586000	5332000	613.87	9964.55	39.63	973.60
17	B30	Pipe	580300	5348250	15908.39	9964.55	147.54	973.60
18	C-14	Pipe	588950	5348100	17047.34	9964.55	1186.80	973.60

Legend:

InDMajFalt:	Individual distance to the nearest major fault
MeDMajFalt:	Mean distance (major faults)(Group 1 and Group2)
InDMinFalt:	Individual distance to the nearest minor fault
MeDMinFalt:	Mean distance (minor faults)(Group 1 and Group2)

The recognition that low magnetic anomalies, as well as high magnetic anomalies, may reflect the presence of kimberlite pipes has doubled the number of potential targets (Sage 1996). According to Sage (1996), the Kirkland Lake area has not yet been prospected for kimberlites displaying anomalous low magnetic signatures. Using the masks described above, the mean magnetic value for Group 1 was found to be –292.64 nT (nanoteslas) and –84.44 nT for Group 2. For the gravity data, the mean gravity value for Group 1 was –46.05 mG/km (milligals per kilometre) and –17.94 mG/km for Group 2. The conductivity and the first vertical derivative data sets only cover 11 kimberlites, all of which belong to Group 1. The mean value for the conductivity for Group 1 was 96.17 mS/m (millisiemens per metre). According to Keating (1996), all known kimberlites in the Kirkland Lake region have a positive conductivity response. Brummer, Macfadyen and Pegg, (1992) stated that kimberlites were also associated with an increase of overburden thickness which was likely caused by recessive erosion of the weathered top of the pipe prior to the last glaciation. This results in a higher apparent conductivity which is a criterion that can be used to reduce the number of possible targets (Keating 1996).

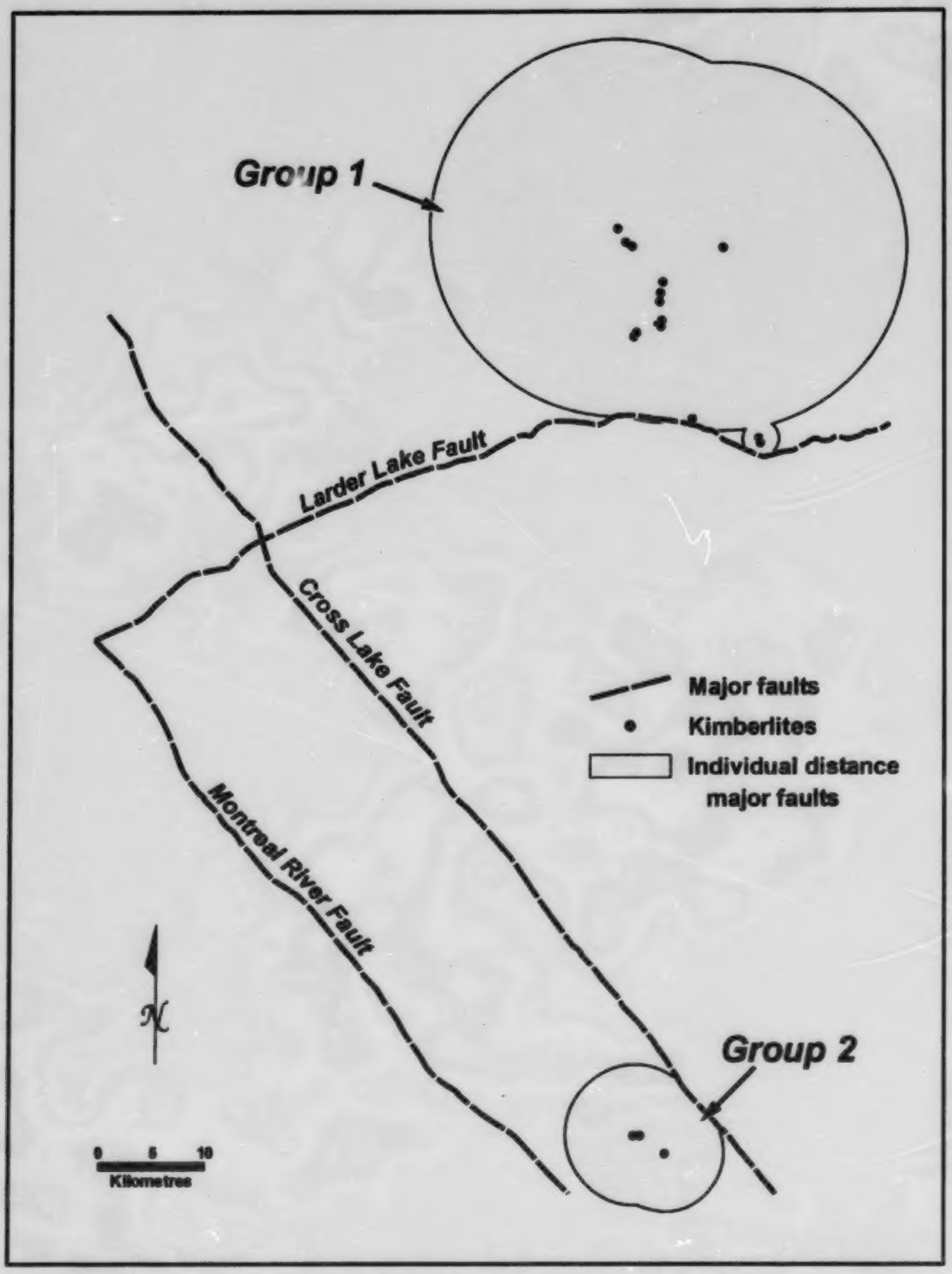
Group 1
Larder Lake Fault
Cross Lake Fault
Montreal River Fault
Major faults
Kimberlites
Individual distance major faults
N
Group 2
0 5 10
Kilometres

Figure 14.3a. Individual distances between kimberlites and major faults.

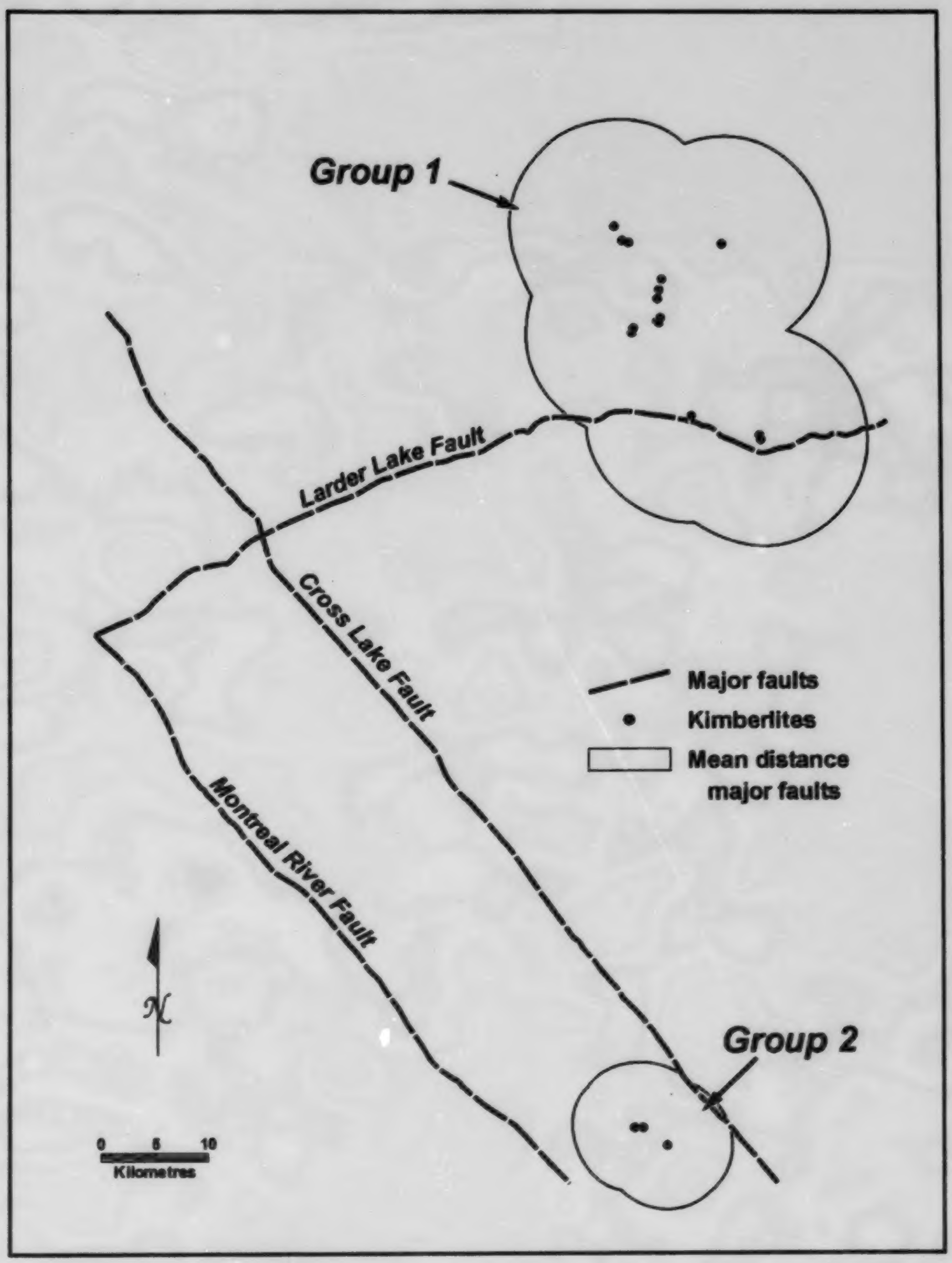
Group 1
Larder Lake Fault
Cross Lake Fault
Montreal River Fault
Major faults
Kimberlites
Mean distance major faults
N
0 5 10
Kilometres
Group 2

Figure 14.3b. Mean distances between kimberlites and major faults.

REMOTE SENSING

Imagery composed of several different beam types were acquired from the Radarsat-SAR data through the Canadian Space Agency under the ADRO-2 initiative. The imagery were selected to maximize the variation in both resolution and angle of incidence as these parameters exhibit great influence on what is detectable on the surface. Table 14.2 contains the particulars of each image type. The imagery were treated using a Gibson speckle filter in order to reduce the effect of speckle (C. Gibson, Ontario Ministry of Natural Resources, personal communication, 2001). Figure 14.4a illustrates the SAR data after treatment with the Gibson speckle filter. The images were then geo-corrected to the planimetric base using a second-order polynomial transform. This ensured coincidence with the content of the GIS to which these data would later be compared.

Table 14.2. Imagery database.

Scene ID	Beam Type	Orbit	Orbit #	Acquisition Date
C001810	Standard 3	Ascending	5794	13-Dec
C0018011	Standard 3	Ascending	5794	13-Dec
C0017983	Standard 4	Descending	10546	11-Nov
C0017984	Standard 4	Descending	10546	11-Nov
C0018087	Standard 4	Descending	10646	11-Nov
C0018088	Standard 4	Descending	10646	11-Nov

Two separate forms of analysis were undertaken: 1) a Prewitt edge detection filter and b) a texture analysis which identifies homogeneous areas. The first form of analysis is based upon the fact that kimberlites tend to be emplaced in proximity to faults of varying dimension. In this study, an edge detection algorithm was used to assess the degree to which faulting could be identified using the various image beam types. The edge detection filter has the effect of enhancing areas where there are abrupt changes in the backscatter intensity from the SAR signal. The results of this process can be seen in Figure 14.4c.

In the second form of analysis, it was assumed that kimberlite pipes may exhibit a control upon the surface in proximity to them, therefore, it was assumed that this effect, if it exists, would be homogeneous. Given this assumption, a texture analysis was undertaken using a homogeneity of variance measure. The results, shown in Figure 14.4b, demonstrate that, for areas with similar backscattering response, the output pixel values are high corresponding to high correlation. For example, Lake Temiscaming is shown as being "bright" due to the similarity of backscattering from the surface of the water. In areas where there is considerable variation in surface cover and morphology, the output pixel values are correspondingly low. It is hoped that the information gathered here, when combined with the GIS database, will demonstrate some coherence for the areas of known kimberlites. Figure 14.4d shows the geographic location of the Group 2 kimberlites.

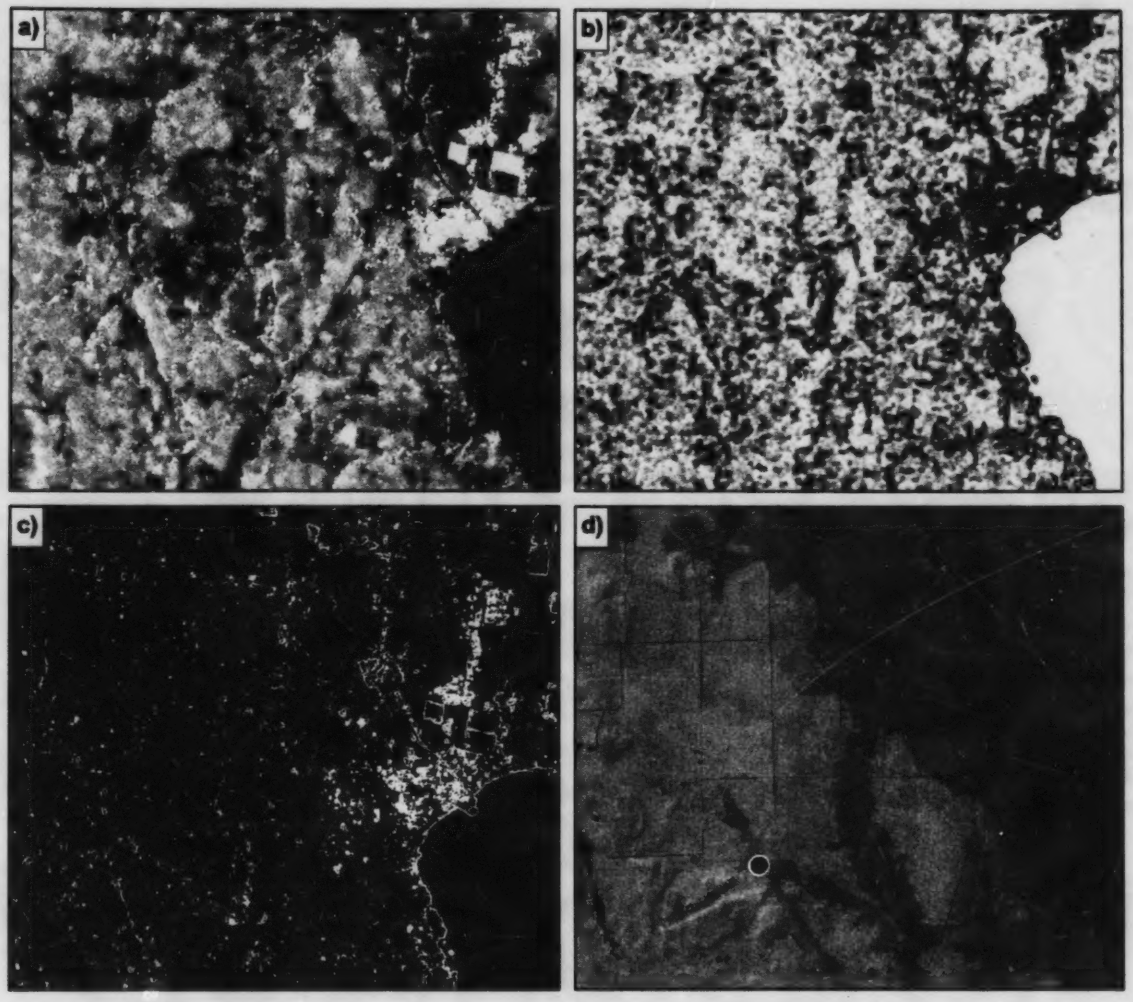

Figure 14.4. Processed SAR data for a standard mode beam 3 or S3 image and corresponding GIS coverage of a portion of the study area: a) SAR data after treatment with a Gibson speckle filter; b) the same image treated using a texture analysis which identifies homogeneous areas; c) image (a) processed with a Prewitt edge detection filter to enhance areas where there are abrupt changes in the backscatter intensity from the SAR signal; and d) a map of a section of the area, represented on the other images, with the location of Group 2 kimberlites indicated by the black dot. Lake Temiscaming is the body of water on the right in all images.

CONCLUSIONS

As previously stated, the final step in the investigation will be to integrate the Radarsat-SAR data, with the GIS data sets. However, before this is done, a Binary Comparison Matrix (BCM) must be used to identify "hotspots" in the geological data, the results of which can then be used to determine if the imagery exhibits corresponding unique characteristics. This will help to determine to what extent the imagery alone can be used to identify potential kimberlite targets. The BCM is a technique that is used to estimate neighbourhood variability of nominal-scale raster data. The method utilizes a binary operator in a 3 by 3 window to perform a neighbourhood analysis. The index is sensitive to both the numbers of classes occurring in a neighbourhood and the frequency of neighbourhood elements in each class (Murphy 1985). It is this latter characteristic which is important in this study. Neighbourhood variability is a parameter important to resource applications using geographic information systems. Variability of nominal-scale data can be measured in a geographic information system with neighbourhood operators. The BCM provides a variability statistic which quantifies the complexity of a neighbourhood as a function of the number of classes and the distribution of neighbourhood elements between the classes (Murphy 1985). The results of the remote sensing analysis will also be converted to nominal-scale data for inclusion in this analysis.

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15. Project Unit 00-012. Precambrian Geology of the Thunder Lake Segment, Wabigoon Area

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INTRODUCTION

Field work carried out during the summer of 2001 completes mapping of the Thunder Lake segment of the Wabigoon area (Beakhouse 2000). The map area straddles the Wabigoon fault, which is interpreted to be a major regional structure separating two contrasting domains within the western Wabigoon Subprovince.

NORTH OF WABIGOON FAULT

The segment of the map area lying to the north of the Wabigoon fault is characterized by alternating panels of southward-facing metavolcanic and metasedimentary rocks (Figure 15.1). All of the metasedimentary units are dominated by wacke with subordinate interlayered siltstone and, with the exception of the Zealand sediments, which are more highly strained, have well-preserved primary structures (even, continuous bedding with graded bedding, scour, rip-up clasts and, less commonly, ripple cross-laminations and load casts). The uppermost Brownridge sediments are interlayered with thin mafic metavolcanic units provisionally interpreted to be similar to metavolcanic rocks within the basal portion of the overlying Brownridge volcanics. Magnetite layers occur within the wacke-siltstone in the lower portion of the Thunder Lake sediments (*see* Figure 15.1) and are the source of prominent aeromagnetic anomalies in the Thunder Lake area. The magnetite layers are closely associated with distinctive garnet-rich (50 to 80% garnet) layers and calc-silicate rock.

The basal portion of the Brownridge volcanics is composed of pillowed and massive mafic metavolcanic rocks together with medium-grained basalt and/or gabbro. In the southeastern portion of Brownridge Township, equigranular mafic metavolcanic rocks are interlayered with distinctive porphyritic mafic to intermediate flows and fragmental metavolcanic rocks. The phenocryst assemblage in these units consists of amphibole (which may, at least in part, be after pyroxene) with or without plagioclase. These rocks are restricted primarily to the area south and southwest of Rafter Lake and do not appear to extend into the western portion of the map area. Berger (1990) described correlative rocks in adjacent Laval Township and presents evidence that they are chemically distinct from other metavolcanic rocks in the area. Previous mapping (Satterly 1941) identified a number of thin felsic metavolcanic units in the upper portion of the Brownridge volcanics in the western half of Brownridge Township. These units are reinterpreted to be variolitic massive and pillowed mafic flows.

The Thunder Lake volcanics, previously interpreted to be metasedimentary rocks (Satterly 1941), consist of quartz ± plagioclase porphyritic felsic metavolcanic rocks that are interlayered with the Thunder Lake sediments (*see* Figure 15.1). Most of the unit is a relatively massive quartz porphyry

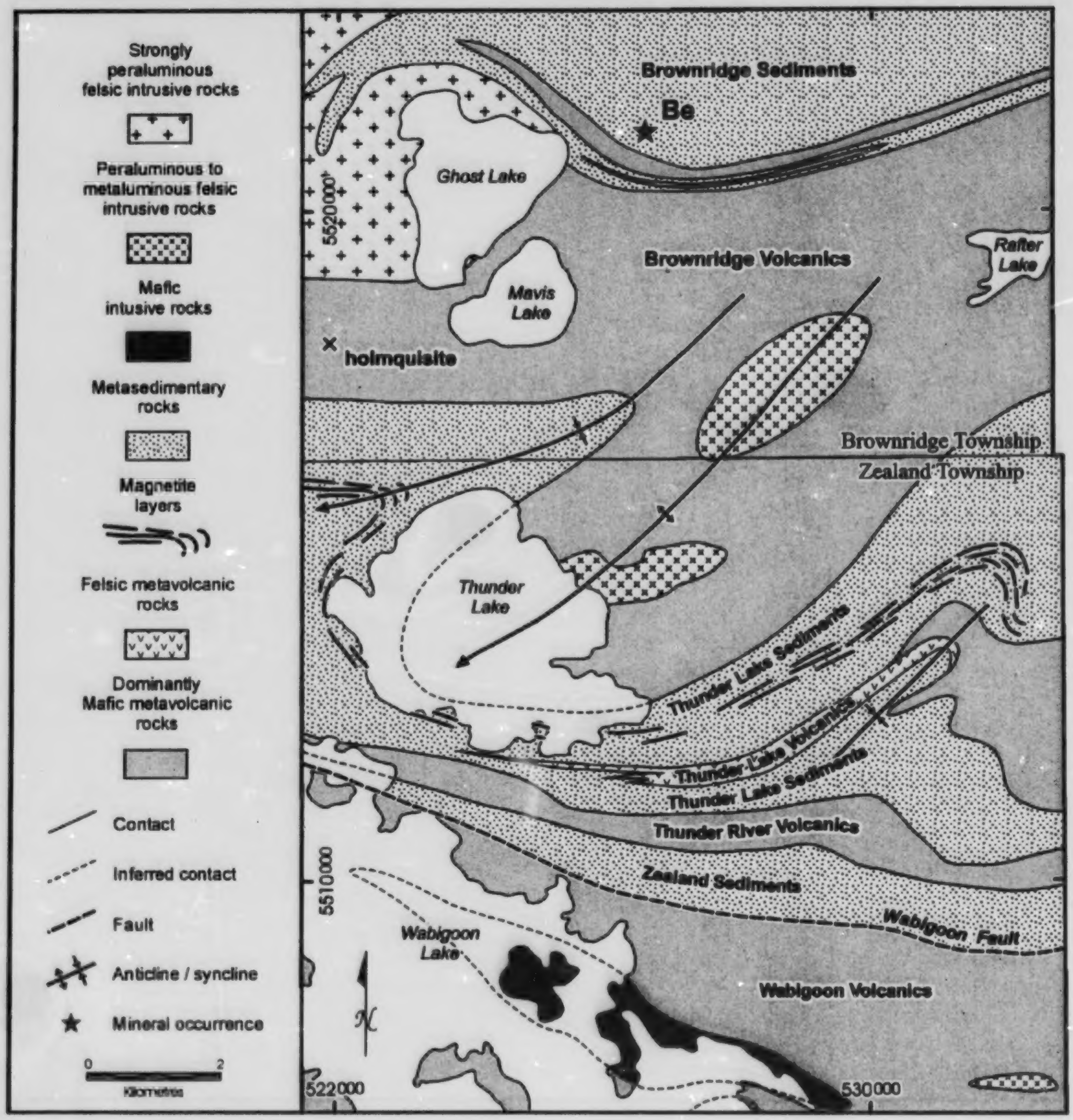
Strongly peraluminous felsic intrusive rocks
Peraluminous to metaluminous felsic intrusive rocks
Mafic intusive rocks
Metasedimentary rocks
Magnetite layers
Felsic metavolcanic rocks
Dominantly Mafic metavolcanic rocks
Contact
Inferred contact
Fault
Anticline / syncline
Mineral occurrence
0
2
Kilometres
Brownridge Sediments
Be
Ghost Lake
5520000
Rafter Lake
Brownridge Volcanics
Mavis Lake
holmquisite
Brownridge Township
Zealand Township
Thunder Lake
Thunder Lake Sediments
Thunder Lake Volcanics
Thunder Lake Sediments
Thunder River Volcanics
Zealand Sediments
Wabigoon Fault
5510000
Wabigoon Lake
N
Wabigoon Volcanics
522000
530000

Figure 15.1. Generalized geological map of the Thunder Lake area.

interpreted to be a crystal tuff on the basis of local occurrences of lapilli-sized, quartz porphyritic felsic volcanic fragments, possible flattened pumice fragments and subtle bedding. The relationship of these felsic metavolcanic rocks to poorly exposed mafic metavolcanic rocks to the east is poorly understood.

The Thunder River volcanics (*see* Figure 15.1) consists of massive and pillowed mafic flows with minor medium-grained mafic to ultramafic units near the northern contact of the sequence.

SOUTH OF WABIGOON FAULT

South of the Wabigoon fault, the Wabigoon volcanics occur within a northward-facing homoclinal sequence. Pillowed, massive and flow-brecciated mafic metavolcanic rocks predominate. Felsic metavolcanic rocks occurring locally in the southwestern portion of the map area, are a minor component, although their extent is partially obscured by water cover. Cherty metasedimentary rocks and intermediate to felsic tuffaceous metavolcanic rocks occur as widely distributed, minor, thin, interflow units.

The Wabigoon volcanics generally have well-preserved primary structures. Exceptions to this generalization include a 200 to 400 m wide zone adjacent to the Wabigoon fault where primary structures are intensely strained and the rocks are altered to chloritic schist. In addition, on a very local scale, some flow contacts and interflow units are more schistose and highly strained than adjacent rocks. This is interpreted to be a consequence of strain being partitioned into more hydrous, inherently weaker zones within the stratigraphy.

STRUCTURE

North of the Wabigoon fault, a moderately to very well-developed mineral foliation (S_1) is generally parallel to primary layering except in 2 locations where it is observed to be parallel to the axial surface of tight to isoclinal folds of the bedding. Bedding and S_1 foliation are deformed, both megascopically and regionally (*see* Figure 15.1) by southwesterly plunging, Z-asymmetric folding (F_2) with attendant development of a second foliation (S_2) parallel to the axial surface of the F_2 folds. In addition, *en échelon* quartz veins and sheets of peraluminous granitic pegmatite are commonly parallel to the S_2 fabric and are interpreted to reflect late extension subsequent to northwest-directed compression that produced the D_2 structures.

South of the Wabigoon fault, fabrics are more heterogeneously developed with many of the Wabigoon volcanics having no readily discernable foliation or strain. Weak to moderate fabrics are developed locally, especially at flow contacts and within thin interflow units. Well-developed, pervasive penetrative deformational fabrics are restricted to within 400 m of the Wabigoon fault suggesting that the development of this foliation may be related to the fault. It is not clear how the intensely developed fabrics near the fault relate to the weaker fabrics observed elsewhere in the Wabigoon volcanics.

Locally, the well-developed fabric within the Wabigoon volcanics adjacent to the Wabigoon fault is deformed into Z-asymmetric minor folds that are similar in style and orientation to the F_2 folds occurring north of the fault. This observation suggests that, assuming the intense fabrics in the Wabigoon volcanics are related to the Wabigoon fault, a component of movement on this fault predates D_2 deformation. The relationship of the earlier fabrics north and south of the Wabigoon fault is uncertain.

ALTERATION

A wide variety of types of alteration are recognized within the map area. A preliminary description and interpretation of the main types follows.

Boron-Lithium Metasomatism Associated with the Ghost Lake Batholith

Previous investigations have identified a close spatial and genetic association between the strongly peraluminous Ghost Lake batholith and both rare-element enriched pegmatites and distinctive metasomatic alteration (Breaks 1989; Breaks and Janes 1991; Breaks and Moore 1992). Boron metasomatism, indicated by the presence of tourmaline, is widespread throughout the northern portion of the map area and is especially conspicuous in the Brownridge volcanics, in the vicinity of Mavis Lake, and in the Brownridge sediments. Tourmaline occurs as tabular to irregular veins, massive fine-grained replacement and as larger euhedral to subhedral porphyroblasts. In some cases, particularly within the Brownridge sediments, it is closely associated with peraluminous granitic pegmatites, which themselves contain trace to significant (<20%) amounts of tourmaline. Tourmaline-bearing peraluminous pegmatite dikes and tabular tourmaline veins are commonly oriented parallel to the S_2 fabric.

Mineralogical evidence of lithium metasomatism is restricted to the vicinity of the Mavis Lake group pegmatites (Breaks and Moore 1992), where a new occurrence of the lithium-bearing amphibole holmquisite (~2 km west of Mavis Lake: UTM 521920E 5517965N (NAD27); *see* Figure 15.1) extends, to the east, a lithium exocontact alteration zone identified by these authors. More widespread garnet and possible scheelite within mafic metavolcanic rocks in this area are also provisionally interpreted to be a manifestation of metasomatic alteration associated with the Ghost Lake batholith.

Calc-Silicate Alteration

Diverse calc-silicate mineral assemblages, consisting of various combinations of plagioclase, diopside, epidote, carbonate, amphibole and garnet, occur in a wide variety of rock types throughout the map area. In some cases, these assemblages may represent metamorphism of marly sediments or syngenetic seawater alteration of mafic metavolcanic rocks.

In other cases, these mineral assemblages represent late alteration assemblages that postdate imposition of the D_1 fabric and may be syn- to post-D_2 deformation. Discrete veins are most common, but irregular zones of diffusely bounded, patchy replacement alteration also occur locally. This style of alteration appears to be restricted to the area north of the Wabigoon fault and is most conspicuous to the east of Thunder Lake in the Thunder Lake volcanics and Thunder Lake sediments.

Garnet

Noteworthy abundances of garnet, that may be indicative of alteration, occur in 2 settings. In the Thunder Lake sediments, extremely garnet-rich (60 to 80% garnet) rocks form layers that are commonly, though not exclusively, closely associated with magnetite layers and calc-silicate mineral assemblages. It is not clear if these layers are indicative of hydrothermal alteration or whether they may represent isochemical metamorphism of unusually aluminous metasedimentary rock.

A second mode of occurrence was observed in several very small outcrops within the Brownridge volcanics approximately 2 km east of Mavis Lake. Here, coarse garnet comprising approximately 25% of the rock occurs within a light coloured, fine-grained matrix. Near the margins of the most intense alteration, observations suggest that the rock being altered may be a variolitic mafic metavolcanic rock.

Quartz Veining and Silicification

Two stages of quartz veining and associated local silicification are recognized to the north of the Wabigoon fault. The earliest veins are parallel to the S_1 foliation and are commonly boudinaged and subsequently folded by D_2 folds. A second set of lenticular, *en échelon* to tabular veins consistently strike southwest with steep dips. These veins are parallel to the axial surface of F_2 folds and are interpreted to be late to post-D_2 deformation. Tourmaline is locally associated with the younger set of veins.

Iron Carbonate ± Quartz Alteration

Iron carbonate, with or without associated quartz, is the predominant alteration assemblage observed in the Wabigoon volcanics. This alteration occurs both as local pervasive replacement and as discrete veins. It is most common in the highly schistose mafic metavolcanic rocks adjacent to the Wabigoon fault, but also occurs locally along flow contacts and in interflow metasedimentary and/or tuffaceous units throughout the Wabigoon volcanics. Iron carbonate veins in the schistose rocks near the Wabigoon fault are parallel to the earlier fabric and folded by the Z-asymmetric minor folds and are consequently interpreted to predate D_2 deformation.

MINERALIZATION

The Thunder Lake area has potential for diverse mineral deposit types including gold hosted in felsic volcanic–sediment assemblages, veins and shear zones, base metal volcanogenic massive sulphide (VMS)-type mineralization and rare metal pegmatite deposits (Beakhouse 2000). Field work carried out during the summer of 2001 has identified several additional areas that may warrant additional investigation.

In addition to the well-established pegmatite group within the Brownridge volcanics near Mavis Lake (Breaks and Moore 1992), numerous pegmatites have been observed within the Brownridge sediments to the east and west of the northern part of Ghost Lake. Many of these pegmatites are relatively complex with coarsely pegmatitic, aplitic and banded aplitic zones and commonly containing coarse, blocky potassium feldspar, as well as muscovite, tourmaline and garnet. One such pegmatite (*see* Figure 15.1) was observed to contain large (<5 cm) beryl crystals in association with coarse tourmaline and garnet along with minor apatite suggesting that some of these pegmatites may be highly evolved. This area warrants consideration for its rare metal potential. More detailed, specialized investigations are being carried out with preliminary results reported elsewhere in this volume (Breaks et al., this volume).

The nature of the garnet-rich alteration assemblages will be investigated further, but this mineral assemblage, together with nearby, scattered, minor gossanous zones, suggest that the Brownridge volcanics may have potential for the discovery of VMS-style mineralization.

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16. Project Unit 99-022. Geology and Nickel-Copper-Platinum Group Elements (PGE) Mineralization of the Entwine Lake Intrusion

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INTRODUCTION

The Entwine Lake intrusion has been the focus of ongoing exploration for nickel-copper-platinum group elements (PGE) mineralization since 1997. This contribution summarizes the second season results of a project, under an Ontario Geological Survey–Mineral Exploration Research Centre Collaborative Project Agreement, designed to further the understanding of the pluton and the nature of mineralization hosted within it. Mapping at a scale of 1:20 000 and a detailed sampling program were undertaken in the summer of 2000. Work carried out in the summer of 2001 includes 1:5000 scale mapping and detailed sampling of the Campbell zone that augments previous work (Arnold, Beakhouse and James 2000). Preliminary results of this work will be discussed and expanded into a MSc thesis at Laurentian University by the author.

GEOLOGY OF THE ENTWINE LAKE INTRUSION

The Entwine Lake intrusion is a Neoarchean polyphase intrusion of monzodiorite and related rocks located 90 km south of the town of Dryden, Ontario (Figure 16.1).

The Entwine Lake intrusion has intruded earlier tonalite to granodioritic gneiss and thin septa of gneissic mafic metavolcanic rocks. Four main intrusive phases have been recognized in the Entwine Lake intrusion: 1) monzonite to quartz monzonite; 2) diorite to gabbro, minor quartz diorite and melagabbro; 3) biotite-rich monzonite to monzodiorite; and 4) potassium feldspar megacrystic monzonite.

The monzonite to quartz monzonite is the oldest intrusive phase based on crosscutting relationships with other phases of the intrusion (Figure 16.2). This unit is distinguished by a well-developed fabric interpreted to be a consequence of both syn-emplacement strain and magmatic flow fabrics. The intensity of fabric development in this phase is much less than that of adjacent country rocks and is predominantly related to magmatic flow. The monzonite is also characterized by a colour index of 20 to 25, defined by mafic minerals such as biotite and amphibole. This intrusive phase does not host sulphide mineralization.

Diorite to gabbro, minor quartz diorite and melagabbro comprise the second intrusive phase. A diorite to gabbro phase hosts the mineralized Campbell zone along the northern margin of the intrusion. During the late 1980s, using diamond drilling, the Campbell zone was explored for its potential as a base metal deposit. In 1995, exploration was renewed on the Campbell zone due to the recent surge in the price of platinum group elements. The diorite to gabbro host rocks at the Campbell zone are texturally massive and characterized by a colour index of 25 to 35, which is locally as high as 70 (Arnold, Beakhouse and James 2000). The rocks contain an augite-amphibole-biotite mafic mineral assemblage

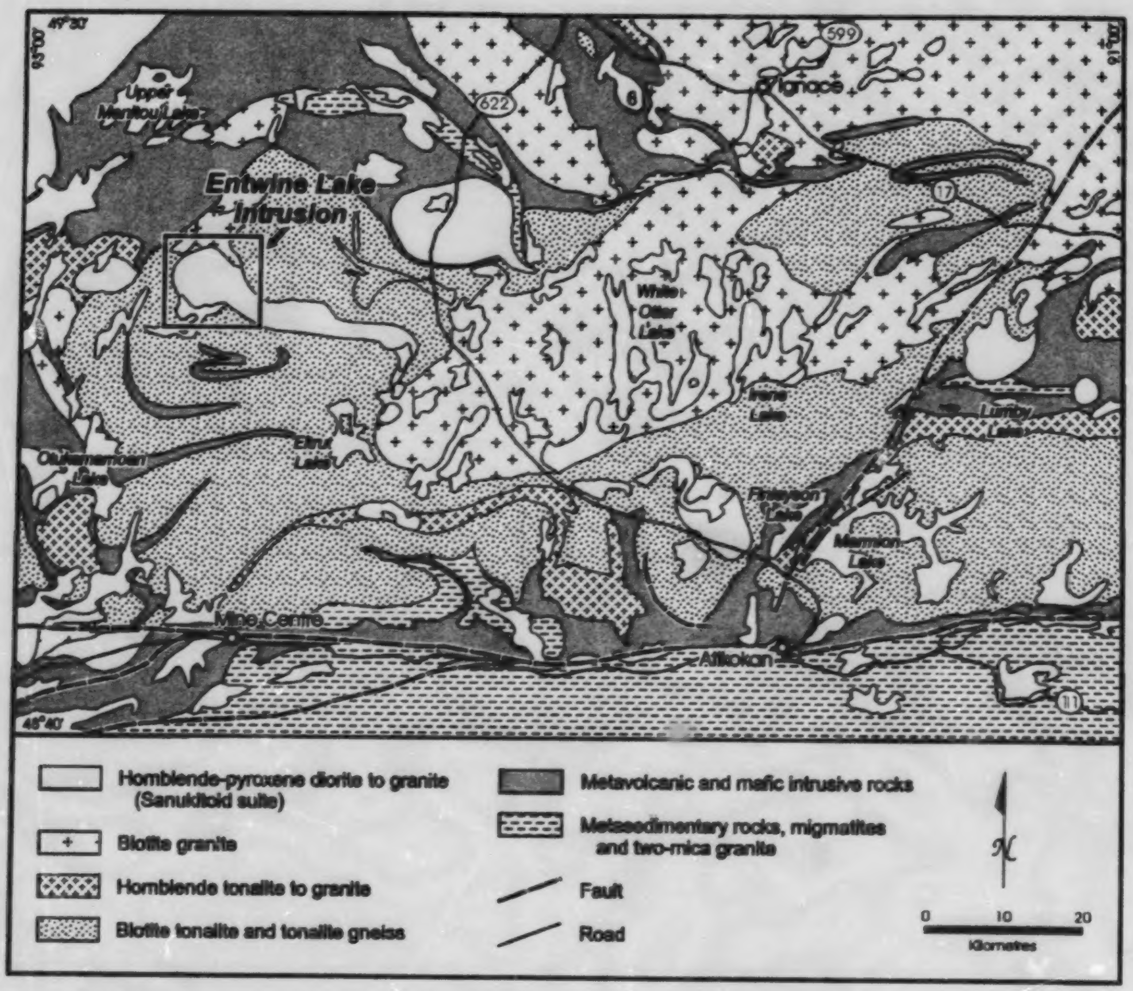

49°30'
93°00'
91°00'
48°40'
Upper Manitou Lake
Entwine Lake Intrusion
599
Ignace
622
6
17
White Otter Lake
Irene Lake
Lumby Lake
Eltrut Lake
Otukamamoan Lake
Finlayson Lake
Marmion Lake
Mine Centre
Atikokan
11
Hornblende-pyroxene diorite to granite (Sanukitoid suite)
Biotite granite
Hornblende tonalite to granite
Biotite tonalite and tonalite gneiss
Metavolcanic and mafic intrusive rocks
Metasedimentary rocks, migmatites and two-mica granite
Fault
Road
N
0
10
20
Kilometres

Figure 16.1. Regional geology of the Central Wabigoon Subprovince and Entwine Lake intrusion location map.

with rare preserved clinopyroxene. All known sulphide mineralization is restricted to this phase. Weak layering, mafic schlieren and associated leucocratic patches are common.

The bulk of the lobate western end of the intrusion consists of a biotite-rich monzonite to monzodiorite unit that does not host sulphide mineralization. Mafic mineralogy includes biotite, amphibole and minor pyroxene. The colour index is commonly 25 to 30 and locally as high as 40 (Arnold, Beakhouse and James 2000). Generally, this phase is homogeneous, medium grained and equigranular, but may contain weak magmatic fabrics defined by mafic minerals. Mafic schlieren were also observed in this phase. Crosscutting relationships indicate that the monzonite to monzodiorite postdates the dioritic and gabbroic rocks as well as the foliated monzonite to quartz monzonite. The gabbroic rocks are interpreted to be decametre-scale inclusions within the monzonite suite of rocks.

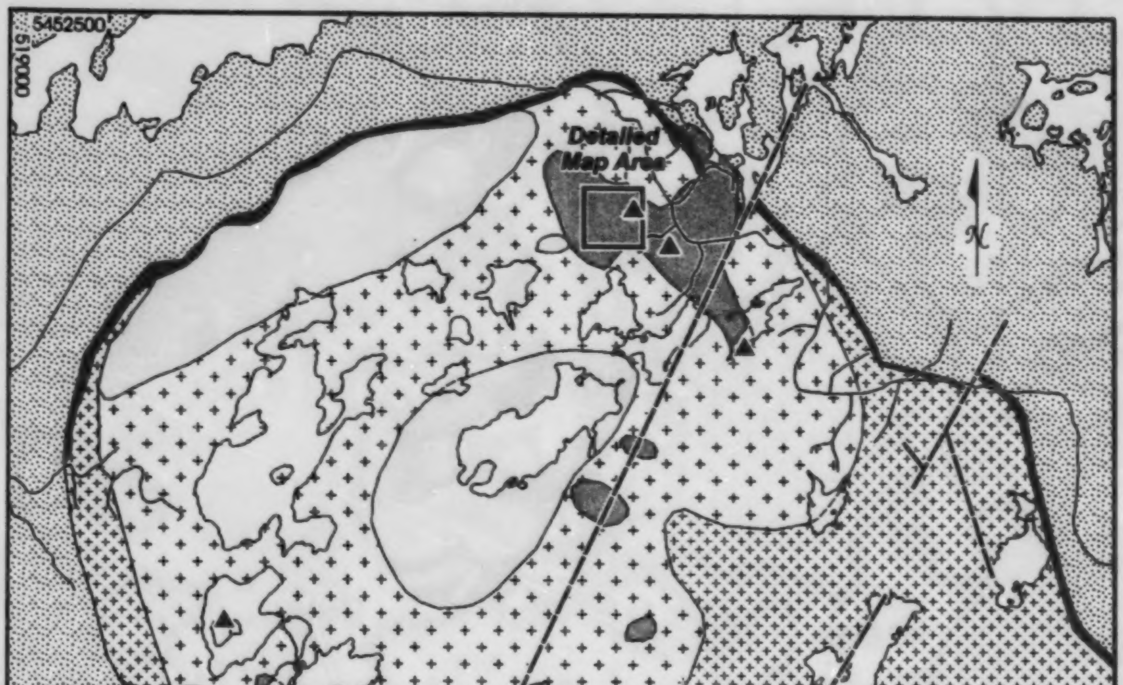

5452500
519000
Detailed Map Area
N
Entwine Lake
530300
5442000
Granodioritic to tonalitic gneiss
Mafic metavolcanic gneiss
Foliated monzonite
Massive medium to coarse grained chalcopyrite, pyrrhotite and magnetite bearing gabbro, diorite quartz monzodiorite
Massive medium grained monzonite
K-feldspar megacryst bearing monzonite
Faults
Sulphide showing > 0.1 g/t (Pt + Pd +Au)
0
2.5
5
Kilometres

Figure 16.2. Schematic geological map of the Entwine Lake intrusion showing geology, distribution of major phases and outline of detailed map area at the Campbell zone.

The youngest phase of the Entwine Lake intrusion is the potassium feldspar megacryst-bearing monzonite. Two large bodies of this phase occur at the core and western margin of the intrusion (*see* Figure 16.2). Smaller bodies occur in other locations as dikes that are tens of metres in thickness. The rock has a typical colour index of 20 to 25 (Arnold, Beakhouse and James 2000) with mafic mineralogy that includes biotite and amphibole. Sulphide mineralization is absent from this phase. A distinctive feature is the presence of ubiquitous potassium feldspar megacrysts. Petrological analysis indicates that the feldspars were formed relatively late since they host inclusions of amphibole, plagioclase, biotite and quartz. This unit often shows megacryst alignment attributed to magmatic flow.

METAMORPHISM AND DEFORMATION

The Entwine Lake intrusion is located at the boundary between the western and central Wabigoon Subprovince, however, plutonic and gneissic country rocks that surround the intrusion are interpreted to be a continuum with the central Wabigoon Subprovince. Therefore, the intrusion has been provisionally included with the central region (Stone 2000). The central Wabigoon Subprovince is predominantly composed of felsic gneissic rocks that have been intruded by large felsic batholiths and late intermediate intrusive bodies such as the Entwine Lake intrusion. Commonly, these batholiths and late intrusive complexes are crescent shaped and are often mantled by septa of amphibole gneiss interpreted to be mafic metavolcanic rocks (Stone 2000).

The Entwine Lake intrusion has been affected by greenschist-facies metamorphism with local, late hydrothermal alteration in the Campbell zone. Structural measurements taken from the felsic gneiss and mafic metavolcanic country rocks suggest that the Entwine Lake intrusion occurs within a regional synclinal structure. There is little structure within the Entwine Lake intrusion, but anisotropy of magnetic susceptibility suggests that the distinctive "tadpole shape" of the pluton is due in part to syn-emplacement ballooning (Arnold and Benn 2000). Late, sinistral, strike-slip faults are interpreted to postdate and transect the intrusion (Stone 2000). Aside from major offset in outcrop, there is relatively little textural evidence for these faults in the field, however, they can be identified from airborne magnetic geophysical surveys (Arnold, Beakhouse and James 2000). Some phases of the intrusion display local brittle-ductile structures that occur most notably along the western margin of the intrusion.

STRATIGRAPHY

Detailed mapping (Figure 16.3) of the Campbell zone has resulted in the recognition of a local stratigraphy based on field observations. The stratigraphy, from bottom to top, consists of the following 4 phases 1) a lower phase of plagioclase mesocumulate gabbro, 2) melagabbro to pyroxenite of variable thickness, 3) a medium- to coarse-grained gabbro, and 4) an anorthositic phase of variable thickness.

Field observations show a continuum between all phases recognized at the Campbell zone. The bottom layer of the Campbell zone is a texturally distinct, plagioclase mesocumulate gabbro. Mauve feldspars are indicative of unaltered gabbro, whereas greenish white feldspars are characteristic of alteration. Primary textures are obscured by the alteration of some plagioclase to fine-grained sericite and chlorite. Pyroxene is an abundant mafic mineral, but it is commonly altered to amphibole that is also rimmed by a second phase of amphibole. Minor oxide minerals such as magnetite and ilmenite are present.

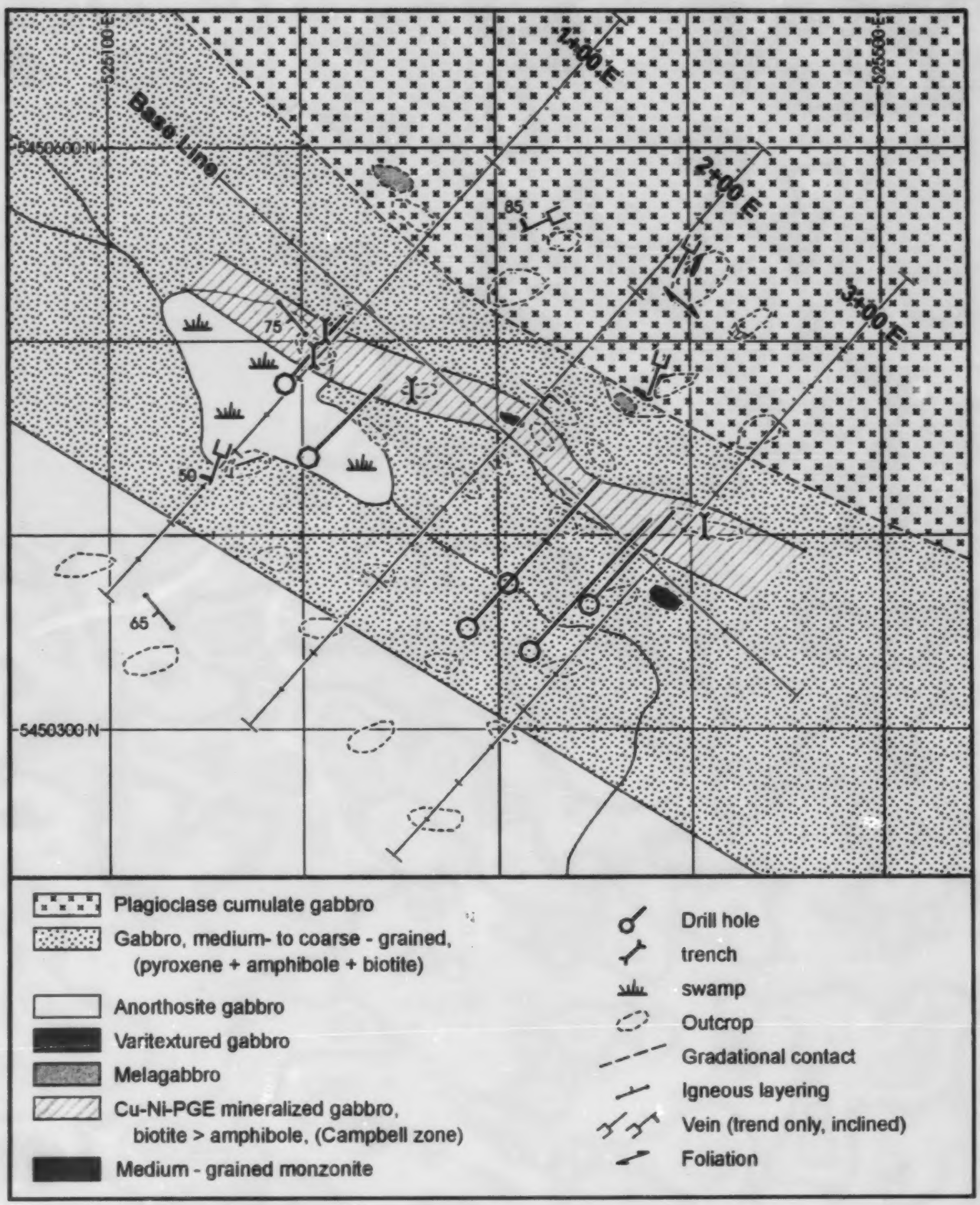

525100 E
525600 E
5450600 N
5450300 N
Base Line
1+00 E
2+00 E
3+00 E
85
75
50
65
Plagioclase cumulate gabbro
Gabbro, medium- to coarse - grained, (pyroxene + amphibole + biotite)
Anorthosite gabbro
Varitextured gabbro
Melagabbro
Cu-Ni-PGE mineralized gabbro, biotite > amphibole, (Campbell zone)
Medium - grained monzonite
Drill hole
trench
swamp
Outcrop
Gradational contact
Igneous layering
Vein (trend only, inclined)
Foliation

Figure 16.3. Detailed geology of the Campbell zone outlining structures and mineralized zones.

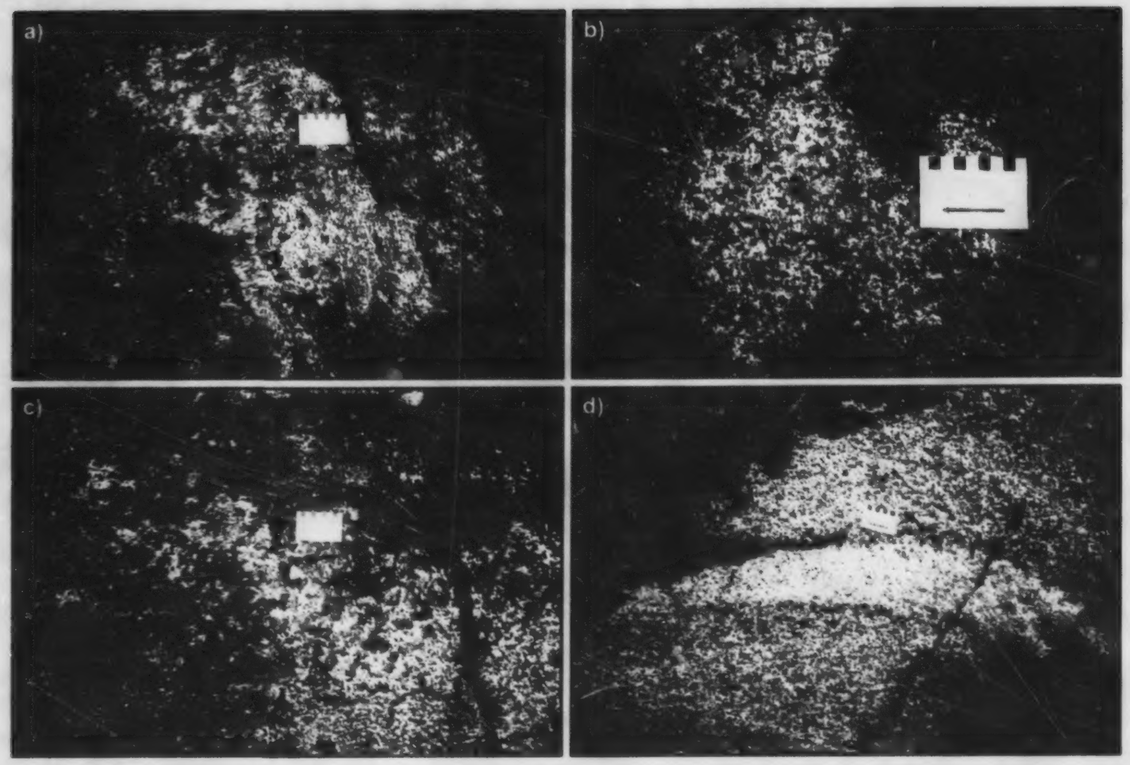
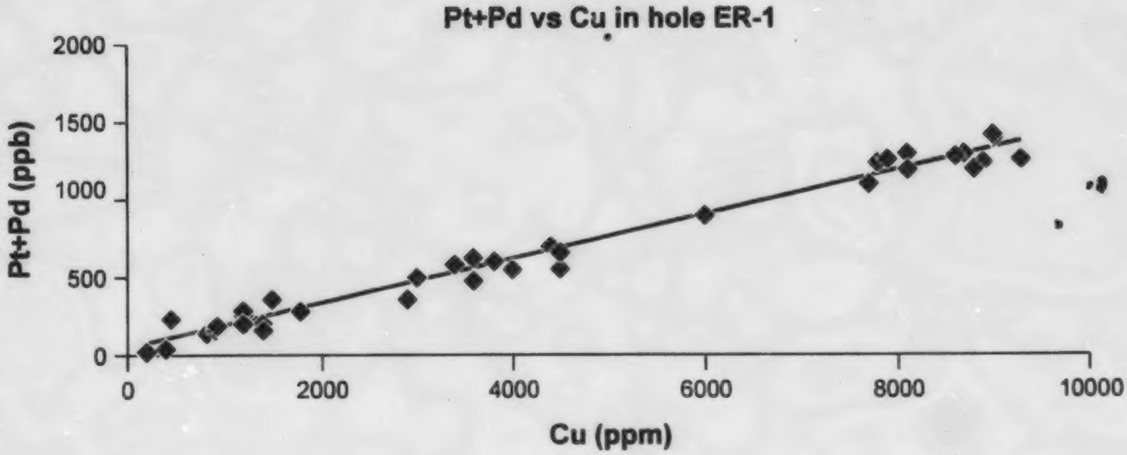


Photo 16.1. Field photographs. a) Photograph of mineralized gossanous patch. b) Gossan representative of mineralized gabbro. c) Varitextured gabbro, volumetrically minor phase, though observed proximal to mineralized gabbro. d) Mafic schlieren and leucocratic pod in gabbro at the Campbell zone.

The melagabbro to pyroxenite phase pinches and swells and shows considerable inconsistency in thickness in surface exposures. To the east of the area depicted in Figure 16.3, the melagabbro becomes more prominent, reflecting the inconsistency in thickness of this layer. Modal mineralogy of this phase has not been determined, however, hand samples have a colour index of 65 to 75. Relict pyroxene, replaced by amphibole and plagioclase, is the main interstitial phase. Sulphide minerals are absent from the melagabbro to pyroxenite.

The medium- to coarse-grained gabbro is host to the PGE mineralized portion of the Campbell zone (*see* Figure 16.3). It is a massive, homogeneous, equigranular gabbro containing pyroxene, amphibole and large books of biotite. Locally, this phase exhibits some cumulate textures and have abundant mafic schlieren and leucocratic patches (Photo 16.1). This phase is variably altered with alteration intensity increasing to the south of the main mineralized zone. Secondary pyrite, chlorite, epidote and minor carbonate are attributed to late hydrothermal alteration. Modal biotite decreases and pyrite increases in abundance with increasing alteration of the gabbro.

Low-grade, disseminated nickel-copper sulphide mineralization is hosted by the medium- to coarse-grained gabbro and is interpreted to represent primary magmatic sulphide mineralization. Associated mineral assemblages such as epidote, amphibole, chlorite and biotite indicate greenschist-facies metamorphism. Mineralized samples contain 5 to 10% chalcopyrite and pyrrhotite with minor pyrite.



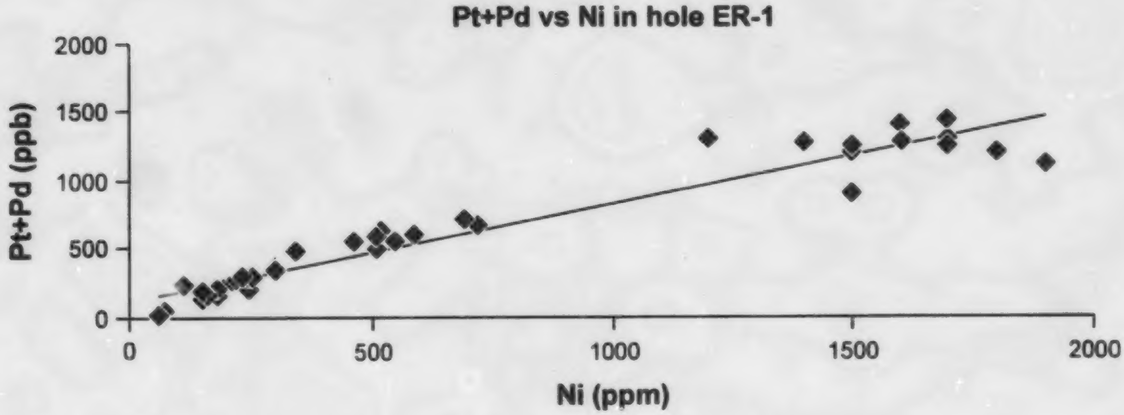


Figure 16. 4. Positive linear correlation between Ni and Cu with Pt+Pd in the Campbell zone hole ER-1.

Diamond-drill core and assay data, provided by Champion Bear Resources Ltd., indicate that concentrations of pyrite are inversely proportional to the abundance of PGE mineralization. The assay data also reveal a strong linear correlation between Cu and Pt + Pd and a weaker correlation between Ni and Pt + Pd at higher PGE levels (Figure 16.4).

A thin zone of texturally massive leucogabbro to anorthosite extends to the south (*see* Figure 16.3) of the Campbell zone and is characterized by pervasive greenschist alteration. Plagioclase is altered to sericite, whereas secondary mafic minerals consist of blue-green amphibole and biotite with no relict pyroxenes. Sulphide mineralization is absent from this phase.

A minor phase of varitextured gabbro (*see* Photo 16.1) was also identified in or near the mineralized gabbro. The varitextured gabbro is not a layer that can be traced continuously on surface and does not appear to be a dike. The significance of this phase is not yet known, however, it is commonly proximal to mineralization (*see* Figure 16.3). Large pyroxene crystals are apparent in hand samples, however, the pyroxenes are replaced by amphibole pseudomorphs.

Table 16.1. Sulphide mineralization assay data from samples in the southern gabbro (Geoscience Laboratories, Ontario Geoservices Centre, Sudbury, Ontario).

Sample Number	Location (UTM)*	Au (ppm)	Pd (ppb)	Pt (ppb)	Ni (%)	Cu (%)
00JA84B	525409E, 5446150N	7.41	2.28	2.14	0.06	0.02
00JA86	524914E, 5444829N	44.60	66.21	38.70	0.08	0.046
00JA86B	524915E, 5444830N	39.00	65.94	36.50	0.07	0.05
00JA87	524956E, 5444894N	37.30	85.76	49.50	0.08	0.057
00JA88	524842E, 5444762N	7.47	22.65	12.23	0.03	0.016

* UTM zone 15, NAD 27

NICKEL-COPPER-PLATINUM GROUP ELEMENTS MINERALIZATION

Past mineral exploration has led to the identification of a number of nickel-copper sulphide mineral occurrences within the Entwine Lake intrusion. Additional occurrences have been identified during the course of this field work. Exploration carried out by Champion Bear Resources Ltd. has identified PGE-enrichment within the Campbell zone. Stone (2000) reported an average grade of 1.0 g/t combined Au, Pt and Pd, 3.8 g/t Ag and 0.5% Cu in the Campbell zone. The Campbell zone also contains palladium-bismuth telluride minerals and electrum associated with greenschist-facies metamorphic mineral assemblages such as epidote, chlorite, actinolite and minor carbonate (Stone 2000).

Future work, by the author, will assess the relationship between hydrothermal fluids and PGE mineralization. Preliminary assessment of sulphide mineral textures and distribution, along with Pd:Pt ratios of 1.5:1, suggest that the PGEs are of magmatic origin and were unaffected by the later hydrothermal alteration.

A second large body of gabbro has been identified along the southern margin of the intrusion north of Entwine Lake. Reconnaissance mapping by the author has discovered a number of trenches and similar mineralization to the Campbell zone (Table 16.1). The pervasive hydrothermal alteration that is evident in the Campbell zone is not apparent in the southern gabbro and an increase in oxide mineral phases was observed in samples from these trenches.

CONCLUSIONS AND FUTURE WORK

Preliminary mapping of the Entwine Lake intrusion has outlined 4 distinct phases of magmatism. It is a polyphase intrusion in which a diorite to gabbro phase has been identified as the host to copper, nickel and PGE magmatic sulphide mineralization. Mapping of the regional geology and detailed mapping of the Campbell zone was completed during the second field season. Identification of a second, large gabbro body along the north shore of Entwine Lake provides further targets for PGE exploration. Bedrock mapping suggests that the gabbro body is ovoid in shape and roughly 2 by 1 km in size. Detailed mapping of this gabbro is recommended. Preliminary results of the Campbell zone mapping and sampling study indicate that some of the magmatic nickel-copper-PGE mineralization is overprinted by late hydrothermal alteration. A strong correlation exists between Cu and Pt + Pd (*see* Figure 16.4), the significance of which will be the focus of subsequent investigation.

ACKNOWLEDGMENTS

The author would like to thank G.P. Beakhouse and R.S. James for their discussions, criticisms and advice on the project. Special thanks are given to Champion Bear Resources Ltd. (A. Pryslak and S. Sears) for their logistical support as well as valuable discussions in the field. Thanks also to C. Wilson for his excellent field assistance.

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17. Project Unit 00-001. Structurally Controlled Mesothermal Gold Mineralization in the Western Beardmore–Geraldton Belt

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INTRODUCTION

This report represents a summary of field observations and data collected during the second summer of a two-year collaborative research project under an Ontario Geological Survey–Laurentian University Graduate Mapping School Agreement. The objectives of the study are to re-evaluate the structural history of the Beardmore–Geraldton Belt (BGB) and to constrain structural controls on mesothermal gold mineralization within the belt. Field work completed during the summer of 2001 focussed on detailed investigation of the characteristics of shear-hosted mesothermal gold mineralization in the western BGB.

GENERAL GEOLOGY

The Beardmore–Geraldton Belt (circa 2.71 Ga) (Figure 17.1) is located in the Archean Superior Province, marking the boundary between the granite-greenstone Wabigoon Subprovince to the north and the metasedimentary Quetico Subprovince to the south. The BGB comprises a sequence of 3 fault-bounded, lower greenschist-facies metavolcanic belts, namely the Northern, Central, and Southern belts (Mackasey 1975, 1976). The belts are east-trending, steeply dipping, and generally north-younging. Each belt consists of a basal mafic metavolcanic unit overlain by metasedimentary rocks. The metavolcanic rocks consist predominantly of massive and pillowed flows of basalt and basaltic andesite, with rare occurrences of tuff and flow breccia. Geochemistry of the 3 mafic metavolcanic belts (Tomlinson et al. 1996) indicate depositional environments of back arc, volcanic arc, and oceanic crust for the northern, central, and southern belts, respectively. The overlying metasedimentary rocks comprise polymictic conglomerate, sandstone, wacke, mudstone, and banded iron formation, forming a southward prograding, fluvial to deep marine, clastic wedge deposited along the southern margin of the Wabigoon Subprovince (Devaney and Williams 1989).

The metasedimentary and metavolcanic belts of the BGB have been previously interpreted as thrust-repeated sequences accreted to the southern margin of the Wabigoon Subprovince during the northward subduction of oceanic crust (Devaney and Williams 1989). Structural mapping of sections of the Northern and Central belts indicates that most deformation structures in the belts were produced by regional dextral transpression across the BGB (DeWolfe, Lafrance and Stott 2000). The belts deformed mainly by pure shear, with dextral shearing becoming localized in regional shear zones such as the Paint Lake deformation zone (Reilly 1987) (Figure 17.2). The dominant structural feature present throughout the BGB is a weak to intense, east-trending, steeply dipping regional foliation, termed S_2 by the authors (DeWolfe, Lafrance and Stott 2000). Many of the regional-scale shear zones are hosts to mesothermal gold mineralization (*see* Figure 17.2).

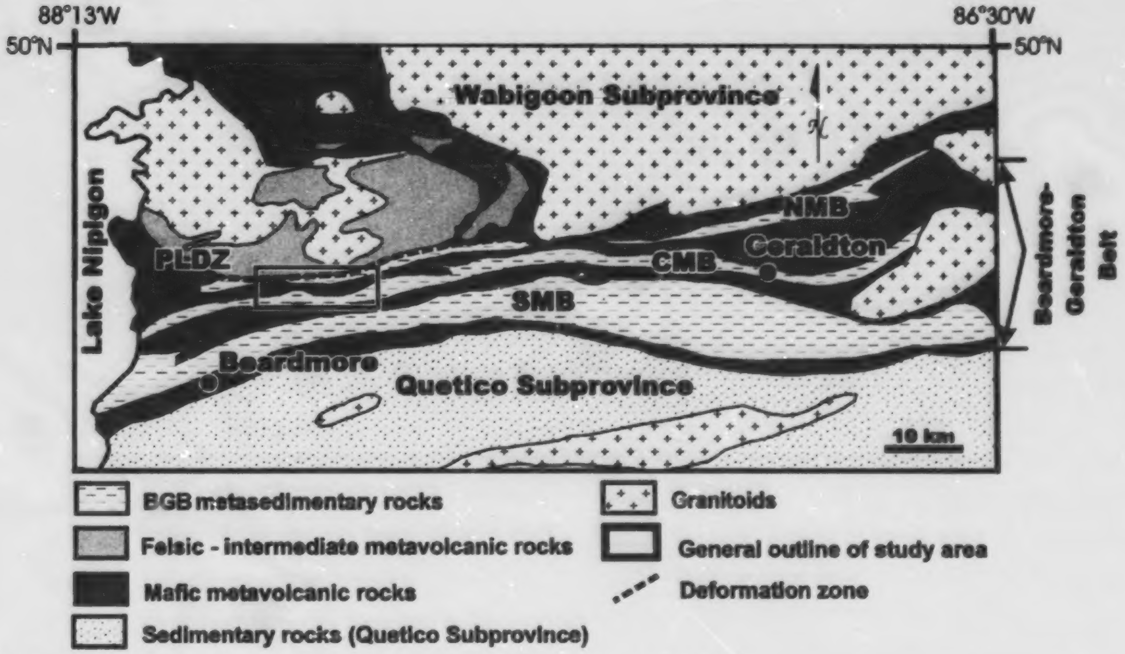
88°13'W
86°30'W
50°N
50°N
Wabigoon Subprovince
N
Lake Nipigon
PLDZ
NMB
Geraldton
CMB
SMB
Beardmore
Quetico Subprovince
10 km
Beardmore-Geraldton Belt
BGB metasedimentary rocks
Felsic - intermediate metavolcanic rocks
Mafic metavolcanic rocks
Sedimentary rocks (Quetico Subprovince)
Granitoids
General outline of study area
Deformation zone

Figure 17.1. Location map for the Beardmore–Geraldton belt (BGB). Abbreviations: NMB, Northern metasedimentary belt; CMB, Central metasedimentary belt; SMB, Southern metasedimentary belt; PLDZ, Paint Lake deformation zone. *Modified from* Williams (1990).

MESOTHERMAL GOLD MINERALIZATION

Two distinct types of structurally controlled gold mineralization occur within the BGB, producing in excess of 4.1 million ounces of gold since the early 1900s (Mason and White 1986). Replacement-type gold mineralization associated with banded iron formation is concentrated within the metasedimentary rocks of the Central and Southern belts (*see* Figure 17.1), and has been the focus for much of the past gold exploration within the belt. Current exploration within the belt is focussing on the potential for large tonnage, low-grade, shear-hosted gold deposits.

Shear-hosted mesothermal gold mineralization occurs throughout the northern mafic metavolcanic belt (*see* Figure 17.1) of the western BGB, with the Bearskin, Foxear, Brookbank, and Cherbourg zones (*see* Figure 17.2) forming a nearly continuous zone of mineralization 7 km in length. Mineralization and associated hydrothermal alteration are focussed along second- and third-order fault splays off the Paint Lake deformation zone (*see* Figure 17.2). The second-order splays generally occur to the south of the main deformation zone, often following lithological contacts and refracting into a direction subparallel with the east-trending Paint Lake fault. Third-order splays are concentrated within the mafic metavolcanic belt where they are oriented both to the northeast and southeast. Near the northern and southern margins of the metavolcanic belt, mineralization appears to be favourably concentrated within the mafic volcanic rocks rather than in the bordering metasedimentary rocks. This is a consequence of the metasedimentary rocks deforming in a ductile manner, while the more massive and competent basalts and basaltic andesites underwent predominantly brittle deformation, thus increasing fluid-flow pathways for the mineralizing hydrothermal fluids. The mafic metavolcanic rocks also provide a more abundant

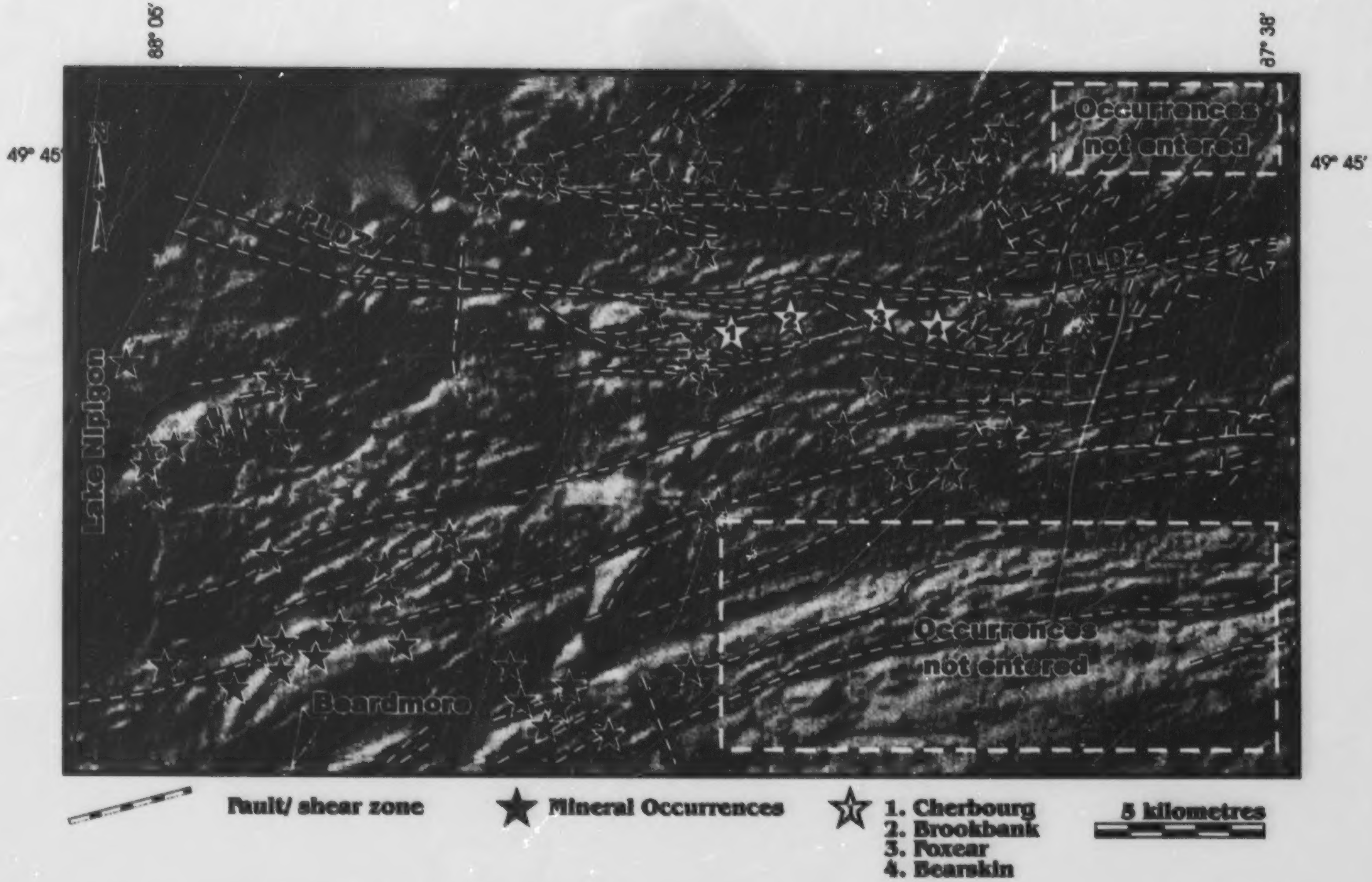
88° 05'
87° 38'
49° 45'
49° 45'
N
Lake Nipigon
PLDZ
PLDZ
Beardmore
Occurrences not entered
Occurrences not entered
1
2
3
4
Fault/ shear zone
Mineral Occurrences
1. Cherbourg
2. Brookbank
3. Foxear
4. Bearskin
5 kilometres

Figure 17.2. Digital topographic map (DTM) for the western BGB showing the spatial relationship between documented mineral occurrences (OGS Mineral Database Inventory) and regional faults and shear zones (structure *compiled from* Mackasey (1975, 1976) and interpreted from DTM). Abbreviation: PLDZ, Paint Lake deformation zone.

Photo 17.1. Cherbourg quartz-carbonate vein, hammer for scale.

0
1
3
5
7
CENTIMETRES

Photo 17.2. Crack-seal textured quartz vein from the Brookbank zone, card for scale.

iron-rich host, promoting sulphidation reactions to precipitate the pyrite and associated gold mineralization within the metavolcanic rocks.

Hydrothermal alteration is both pervasive and vein type, and includes ankerite, potassium feldspar, quartz, sericite, chlorite, and epidote. Alteration within the shear zones is dominated by strong to intense ankerite flooding. Mineralization appears to be concentrated in zones displaying strong to intense ankerite, potassium feldspar, and quartz alteration.

In zones where deformation is moderate to strong, quartz and or quartz-carbonate veins commonly occur in conjunction with strong to intense, pervasive alteration. Vein quartz is typically milky white to smoky grey, while the carbonate component may consist of either orange-brown ankerite or white to pink calcite. The veins range from millimetres up to several metres in thickness (Photo 17.1) and are consistent in orientation, relative to the regional S_2 foliation, with dextral shear-related foliation-parallel veins, tensional veins, and "P-fracture"-filled veins ("P" is a type of Riedel shear in a brittle fault zone; see Passchier and Trouw (1996, p.128)). Tensional veins typically display crack-seal (Photo 17.2) and laminated textures indicative of multiple vein-filling events, while foliation parallel veins and "P-fracture" veins are typically boudinaged or brecciated. In zones where deformation is most intense, quartz veins are typically absent, with the dominant features being intense pervasive ankerite and potassium feldspar alteration, intense regional S_2 foliation, and well-developed dextral shear bands. Sulphide mineralization within the BGB is characterized by 2 overprinting coarse- and fine-grained pyrite phases, while minor disseminated chalcopyrite and rare medium-grained arsenopyrite are also present. Petrographic and fluid inclusion studies by Kowalski (1993) indicate that the gold mineralization is associated with the fine-grained pyrite phase. The sulphide mineralization occurs both as vein mineralization in conjunction with the quartz-carbonate veins, and as disseminated pyrite mineralization in the shear zones.

RECOMMENDATIONS FOR GOLD EXPLORATION

Exploration for mesothermal gold mineralization within the western BGB should focus on identifying zones where concentrations of second- and third-order fault splays exist within the mafic metavolcanic rocks. Gold mineralization is not restricted to the mafic metavolcanic rocks, but their chemical and mechanical characteristics combine to form a favourable environment for mineralization to occur. Mineralization is associated with fine-grained pyrite occurring in both shear zones and quartz veins. Disseminated pyrite with intense pervasive ankerite and potassium feldspar alteration is characteristic of the majority of the mineralized shear zones. Exploration for vein-hosted mineralization should focus on pyrite-bearing quartz-carbonate veins related to the regional dextral deformation event and displaying multiple vein-filling stages such as crack-seal textures.

ACKNOWLEDGMENTS

Funding for this project is provided by the OGS under the Ontario Geological Survey–Laurentian University Graduate Mapping School Agreement. Additional funding is provided by Natural Sciences and Engineering Research Council of Canada (NSERC) and Lithoprobe grants awarded to Dr. B. Lafrance at Laurentian University. Thank you to Amy Kerckhoff for her excellent assistance in the field; Ontex Resources and St. Anthony Resources for access to their properties; Gerry White and John Mason (OGS Resident Geologist Program) and to the prospectors of the Beardmore area.

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18. Project Unit 89-47. Geochronology of Several Greenstone Belts in the Sachigo Subprovince, Northwestern Ontario

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INTRODUCTION

In 1988, G.M. Stott and I.A. Osmani collected a suite of samples to obtain U/Pb zircon ages of metavolcanic and metasedimentary sequences in several key greenstone belts in the North Caribou terrane and in other more northerly parts of the Sachigo Subprovince (Figure 18.1). These, along with other samples collected by A. Cortis, P. Thurston, E. de Kemp and D. Davis, were analyzed by the senior author and colleagues at the Jack Satterly Geochronology Laboratory, Royal Ontario Museum. An unpublished report of the results of the U/Pb geochronology for these samples was submitted to the Ontario Geological Survey (Davis 1999). The following summary of the ages obtained from diverse parts of the Sachigo Subprovince is from that report. The purpose of this article is to make the basic results publicly available.

Of the original 16 samples submitted, 12 samples (Tables 18.1 and 18.2) yielded sufficient zircons to provide us with results as illustrated in Figures 18.2 and 18.3. The other 4 samples, from the Swan Lake, Ponask Lake and North Caribou greenstone belts, yielded no zircons or a few rounded grains that are likely to be xenocrysts and were not analyzed.

GEOLOGICAL DESCRIPTIONS

North Caribou Greenstone Belt

Samples were collected to help unravel the age complexity of the North Caribou greenstone belt. There were several objectives to this sampling: 1) to determine if the dominantly basaltic rims (North Rim and South Rim tectonic assemblages) north and south of the central metasedimentary syncline are the same age; and 2) to further clarify the age of the Mesoarchean platform-type Keeyask assemblage containing quartz arenite beds and komatiite flows.

Six samples from this belt yielded results. These samples are described as follows with location numbers from Figure 18.1:

DD87-8: Location 1. A rhyolitic tuff from the west shore of Opapimiskan Lake. This unit is interpreted to lie within the South Rim assemblage (Thurston, Osmani and Stone 1991).

DD87-9: Location 2. A thin, felsic volcaniclastic unit or tuff interbedded with basalt from the south shore of McGruer Lake. This unit lies within the North Rim assemblage (Thurston, Osmani and Stone 1991).

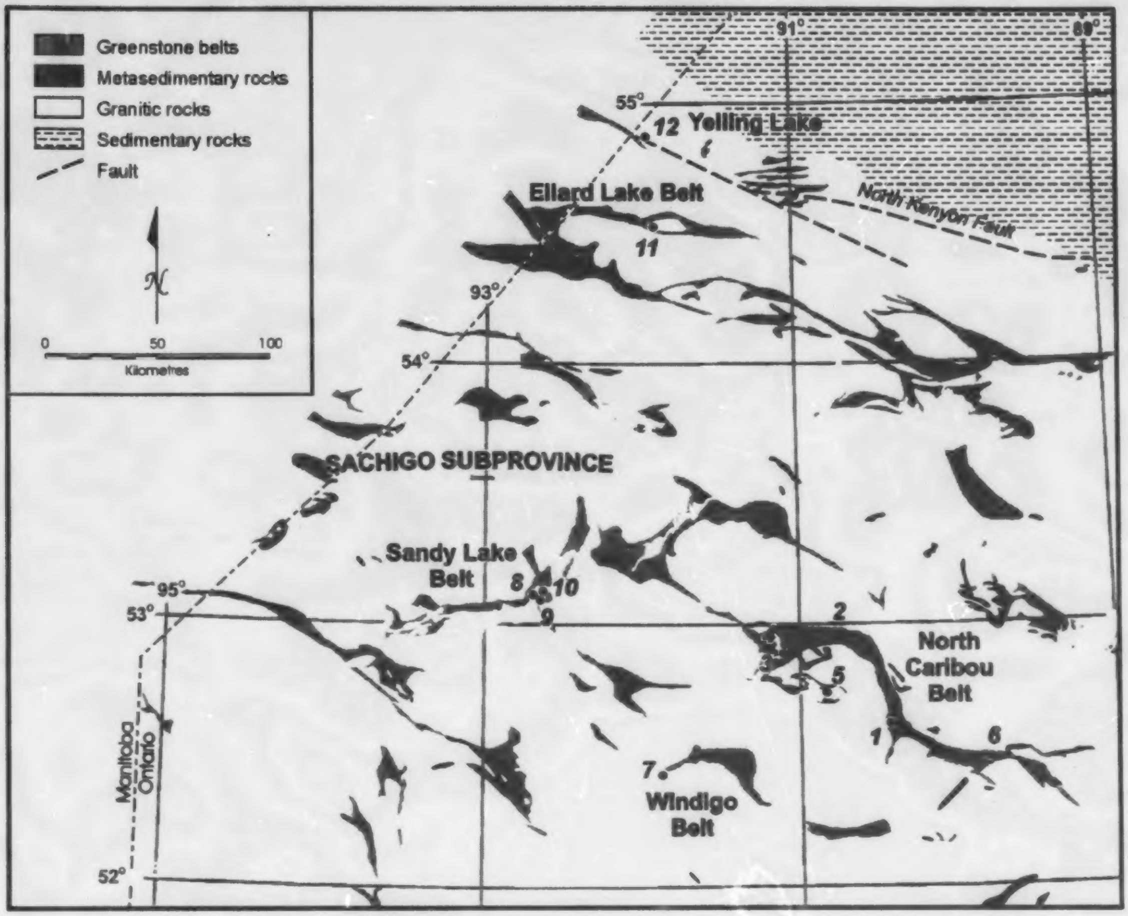
Greenstone belts
Metasedimentary rocks
Granitic rocks
Sedimentary rocks
Fault
N
0
50
100
Kilometres
91°
89°
55°
12
Yelling Lake
Ellard Lake Belt
North Kenyon Fault
11
93°
54°
SACHIGO SUBPROVINCE
Sandy Lake Belt
8
10
9
95°
53°
2
North Caribou Belt
5
1
6
7
Windigo Belt
Manitoba
Ontario
52°

Figure 18.1. Locations of several greenstone belts in the Sachigo Subprovince. Numbers correspond to samples listed in Table 18.1.

ERIC89: Location 3. A quartz porphyry dike that transects the Keeyask ultramafic metavolcanic unit, southwest of Eyapamikama Lake. The dike provides a minimum age for the deposition of the Mesoarchean Keeyask platform-type assemblage.

PT97-1: Location 4. A quartz-rich sandstone near the basal part of the Eyapamikama assemblage at the southwest end of Eyapamikama Lake.

88GRS113E: Location 5. Biotite granodiorite from a western phase of the North Caribou pluton, from the westernmost part of North Caribou Lake. This phase lies close to the large tonalite gneiss dome to the southwest of the pluton.

88GRS114: Location 6. Quartz arenite clasts from a platform-type sequence—the Zeemel–Heaton assemblage, at Heaton Lake in the southeastern part of the North Caribou belt. The conglomerate outcrop is dextrally sheared with shearing concentrated in pelitic interlayers and pebbly sandstone beds. Age distribution of detrital zircon grains from clastic metasedimentary units at opposite ends of the greenstone belt provides some constraints to the depositional history of these units.

Table 18.1. Geochronology sample descriptions and locations (*see* Figure 18.1 for location numbers).

Location No.	Sample	Description	Location	UTM Coordinates		
				Zone	Easting	Northing
	North Caribou Greenstone Belt					
1	DD87-8	Rhyolitic tuff, South Rim assemblage	Opapimiskan Lake - west shore	15	673380	5834000
2	DD87-9	Felsic to intermediate volcaniclastic unit, North Rim assemblage	McGruer Lake - south shore	15	647250	5871500
3	ERIC89	Quartz porphyry dike cutting Keeyask ultramafic volcanics	within Keeyask assemblage, SW of Eyapamikama Lake	15	627650	5862200
4	PT97-1	Sandstone within conglomerate, Eyapamikama assemblage	southwest end of Eyapamikama Lake	15	628350	5862600
5	88GRS113E	Biotite granodiorite, North Caribou pluton	North Caribou Lake, west of Terry Island	15	644560	5844690
6	88GRS114	Quartz arenite clasts, Zeemel–Heaton assemblage	Heaton Lake - south shore, SE end of North Caribou belt	16	307000	5820200
	Windigo Lake Area					
7	88GRS119B	Biotite trondhjemite	Shinbone Lake, south of Windigo greenstone belt	15	576020	5806800
	Sandy Lake Greenstone Belt					
8	88GRS398	Large quartzite boulder in 1 m wide conglomerate bed, mid fan	Sandy Lake island at east end	15	524400	5882840
9	88GRS408	Pebbly arkose of granodiorite-rich channel scour	Sandy Lake, small island at east end	15	524620	5882250
10	DD97-1	Feldspar porphyry diorite dike in quartz arenite	Sandy Lake, close to shoreline on east end of lake	15	525420	5883200
	Ellard Lake Area					
11	88GRS501	Dacitic tuff	Ellard Lake - south end	15	572790	6040110
12	88GRS503	Granodiorite	west side of Yelling Lake on North Kenyon Fault	15	574910	6077790

Windigo Lake Area

In the absence of a suitable volcanic sample to date, a single sample was collected close to the Windigo greenstone belt in an attempt to find some evidence of a Mesoarchean magmatic history in this part of the North Caribou terrane.

88GRS119B: Location 7. Biotite trondhjemite south of Shinbone Lake at the southwest end of the Windigo Lake greenstone belt. The rock is fine grained and recrystallized with a moderate to weak foliation and cut by trondhjemite dikes that have been affected by the same recrystallization and foliation.

Sandy Lake Greenstone Belt

There is a substantial deposit of quartz arenite and conglomerate at the east end of the Sandy Lake greenstone belt known as the Keewaywin formation which is interpreted to be derived mainly from the underlying felsic plutonic basement. This metasedimentary section was the subject of a MSc thesis study by Cortis (1991). Two samples from the metasedimentary rocks were obtained along with a sample from a dike within the quartz arenite.

88GRS398: Location 8. A large quartzite boulder from a 1 m thick bed of conglomerate in the Keewaywin Formation, interpreted by Cortis (1991) to lie within a mid-portion of a submarine fan sequence. Sample is from the west side of an island in eastern Sandy Lake.

88GRS408: Location 9. Pebbly arkose from a granodiorite-rich channel scour in the clastic metasedimentary Keewaywin Formation. Sample from the northeast side of another small island south of sample 398, eastern Sandy Lake.

DD97-1: Location 10. Feldspar porphyritic diorite dike, 2 m wide, intruding a mafic dike that crosscuts the quartz arenite beds of the Keewaywin formation near the northeast shore of Sandy Lake.

Ellard Lake Area

Results were obtained from 2 samples from the Ellard Lake area in the northwestern part of the Sachigo Subprovince. It was intended to determine whether magmatic ages decrease northward away from the North Caribou terrane in a similar pattern to the southward decrease in age across the Uchi Subprovince (Stott and Corfu 1991).

88GRS501: Location 11. Feldspar porphyritic dacitic tuff. The tuff is very schistose and interbedded with 30 cm to 1.5 m thick andesitic tuff to tuff breccia containing bomb-sized clasts of dacitic composition. Sample is from a small outcrop at the south end of Ellard Lake.

88GRS503: Location 12. Granodiorite to tonalite, strongly sheared and containing 15% chlorite with epidote, saussuritized feldspar augen and thin lenses and ribbons of quartz. The sample is from the west side of Yelling Lake, on the North Kenyon Fault.

METHODS

Samples were pulverized with a jaw crusher followed by a disk mill. Powders were passed over the Wilfley® table to concentrate heavy minerals. Further heavy mineral separation was carried out by density separations with bromoform and methylene iodide and paramagnetic separations with a Frantz® separator. Final sample selection was by hand picking under a microscope. Exterior surfaces of selected zircon grains were removed by air abrasion. Weights of small zircon fractions were estimated by eye, a process that is been found usually accurate to about ±50%. This affects only uranium and lead concentrations, not age information, which depends only on isotopic ratio measurements.

Zircon was dissolved using hydrofluoric acid in Teflon™ bombs at 200°C, after being washed in HNO_3. A $^{205}Pb/^{235}U$ spike was added to the dissolution capsules during sample loading. For grains weighing less than 5 µg, solutions were converted to hydrochloric acid then dried down and loaded directly onto the mass spectrometer filaments. These loads produced strong stable lead signals. For larger grains, purification of lead and uranium was carried out in hydrochloric acid using 0.05 mL anion exchange columns.

Lead and uranium were loaded together on rhenium filaments using silica gel and analyzed with a VG354 mass spectrometer in single collector mode. Most of the measurements were made using a Daly collector. The mass discrimination correction for this detector is constant at 0.40%/AMU. Thermal mass discrimination corrections are 0.10%/AMU.

RESULTS

Results of isotopic measurements are given in Table 18.2 (errors at 2 sigma (σ)) and plotted on Figures 18.2 and 18.3. Data regressions are based on the program of Davis (1982). Probabilities of fit would be expected to be around 50% on average. Age errors based on regression are quoted at the 95% confidence level. Error ellipses in the figures are given at the 2σ level. Common lead in zircon was corrected using the isotopic composition of laboratory blank. Th/U estimates are based on measured $^{208}Pb/^{206}Pb$ ratios and $^{207}Pb/^{206}Pb$ ages.

Because single abraded zircons have been analyzed, often from complex populations, ages are usually based on averaging $^{207}Pb/^{206}Pb$ ages of near-concordant data points. "Near-concordant" means data points that are less than 1% discordant. Such data from abraded zircon grains usually produce consistent $^{207}Pb/^{206}Pb$ ages, whereas unabraded zircons often record severe secondary lead loss at ages in the range 0 to 600 Ma.

DD87-8 Opapimiskan Lake Rhyolite Tuff (Figure 18.2a)

The sample yielded only a small amount of zircon, generally as large fresh multifacetted crystals and fragments.

Two single euhedral zircons and a fraction with 2 grains, colourless and brownish, were analyzed. This gave 3 near-concordant overlapping data points with an average age of 2981.9 ± 0.8 Ma. This is the best estimate for the age of eruption.

Table 18.2. U/Pb isotopic data on zircons from the Sachigo Subprovince.

No.	Fraction	Weight (mg)	U (ppm)	Th/U [a]	PbCom [b] (pg)	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{206}Pb}{^{238}U}$	2σ	$\frac{^{207}Pb}{^{235}U}$	2σ	$^{207}Pb/^{206}Pb$ Age (Ma)	2σ	% Disc. [c]
	DD87-8 Rhyolite tuff, Opapimiskan Lake												
20	1 Ab zr, eq, pale pink, incl, crk	0.004	88	0.94	1.0	3044	0.5876	0.0023	17.846	0.074	2982.6	1.6	0.1
21	1 Ab zr, spr, clr, crk	0.008	47	1.10	2.0	1604	0.5844	0.0023	17.744	0.074	2982.2	1.5	0.6
22	2 Ab zr, euh, clr & brn	0.006	47	1.00	0.8	3135	0.5859	0.0023	17.776	0.073	2981.0	1.5	0.3
	DD87-9 Felsic volcaniclastic, McGruer Lake												
13	1 Ab zr, euh, spr, clr	0.010	28	0.53	0.7	3446	0.5871	0.0013	17.801	0.046	2980.0	1.5	0.1
14	1 Ab zr, euh, clr	0.004	40	0.58	0.4	3271	0.5811	0.0024	17.463	0.075	2965.7	1.7	0.5
15	1 Ab zr, wrnd, mot	0.020	50	0.26	0.4	20266	0.5585	0.0016	15.818	0.049	2869.8	1.8	0.4
	ERIC89 Quartz porphyry, Keeyask Lake												
16	1 Ab zr, mot	0.002	87	0.33	0.8	1695	0.5675	0.0017	16.335	0.054	2896.0	1.5	-0.1
17	1 Ab zr, brn	0.001	233	1.50	6.7	271	0.5573	0.0012	15.720	0.055	2863.2	3.4	0.3
18	1 Ab zr, lpr, brn, crk	0.002	218	0.52	1.4	2262	0.5555	0.0015	15.669	0.046	2863.0	1.6	0.6
19	1 Ab zr, brn, crk	0.001	976	0.29	100	70.21	0.5392	0.0030	14.730	0.171	2810.8	17.7	1.3
	PT97-1 Sandstone, Eyapamikama Assemblage												
1	1 Ab zr, subrnd, flat, brn	0.008	105	0.68	1.1	6347	0.5815	0.0029	17.670	0.088	2983.4	2.0	1.2
2	1 Ab zr, subrnd, spr, brn	0.006	82	0.85	1.0	3989	0.5870	0.0019	17.810	0.058	2981.1	2.1	0.2
3	1 Ab zr, subrnd, pale brn, frag	0.010	94	0.66	1.1	7407	0.5882	0.0014	17.837	0.047	2980.3	2.0	-0.1
4	1 Ab zr, euh, spr, brn	0.0015	77	0.94	0.8	1155	0.5884	0.0019	17.834	0.060	2979.4	2.2	-0.2
5	1 Ab zr, subrnd, melt incl, crk	0.015	86	0.49	2.9	3629	0.5773	0.0016	17.315	0.050	2962.6	2.0	1.1
6	1 Ab zr, subrnd, pale brn, incl	0.007	46	0.58	1.1	2299	0.5807	0.0018	17.416	0.056	2962.5	2.1	0.5
	0113E Granodiorite, North Caribou Lake												
23	1 Ab zr, mot, melt incl	0.020	343	0.57	5.2	11328	0.5920	0.0021	18.365	0.070	3016.9	1.4	0.8
24	1 Ab zr, brn	0.001	360	0.20	0.4	7901	0.5761	0.0021	17.108	0.063	2946.5	2.0	0.6
25	1 Ab zr, euh,eq, clr	0.010	60	0.58	0.7	6271	0.5584	0.0017	15.760	0.053	2864.0	1.6	0.2
26	1 Ab zr, euh, eq, clr	0.002	54	0.68	0.3	2665	0.5573	0.0028	15.729	0.081	2863.9	2.1	0.4
27	1 Ab zr frag, brn	0.003	289	0.28	0.6	11502	0.5583	0.0013	15.728	0.042	2861.0	1.5	0.1
	88GRS114 Quartz arenite clasts, Heaton Lake												
7	1 Ab zr, spr, mot	0.020	63	0.74	6.8	1543	0.5857	0.0028	17.773	0.087	2981.2	1.7	0.4
8	1 Ab zr, eq, brn	0.002	120	0.62	0.8	2394	0.5874	0.0020	17.821	0.064	2981.0	1.6	0.1
9	1 Ab zr, eq, pale brn	0.010	73	1.01	0.6	10146	0.5867	0.0020	17.791	0.066	2980.1	1.5	0.2
10	1 Ab zr, eq, flat, clr	0.010	27	0.64	0.4	4712	0.5567	0.0017	15.639	0.052	2856.4	1.6	0.1
11	1 Ab zr, spr, clr	0.020	12	0.49	1.8	1014	0.5530	0.0026	15.504	0.075	2853.1	1.9	0.7
12	1 Ab zr, eq, clr, melt incl	0.005	21	0.69	0.9	910	0.5557	0.0017	15.576	0.053	2853.0	2.2	0.2

Table 18.2. Continued

No.	Fraction	Weight (mg)	U (ppm)	Th/U [a]	PbCom [b] (pg)	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{206}Pb}{^{238}U}$	2 σ	$\frac{^{207}Pb}{^{235}U}$	2 σ	$^{207}Pb/^{206}Pb$ Age (Ma)	2 σ	% Disc. [c]
	0119B Biotite trondhjemite, Shinbone Lake												
42	1 Ab zr, flat, brn, crk	0.003	161	0.34	0.4	11149	0.6019	0.0019	18.902	0.064	3036.5	1.7	0.0
43	1 Ab zr, pale brn, crk	0.005	172	0.39	3.5	2146	0.5909	0.0017	18.518	0.057	3033.1	1.6	1.6
44	1 Ab zr, mot	0.010	524	0.22	0.7	59094	0.5832	0.0013	17.152	0.044	2930.9	1.4	-1.3
45	1 Ab zr, flat, mot	0.004	836	0.47	3.9	6030	0.5473	0.0014	15.040	0.043	2820.4	1.6	0.3
46	1 Ab zr, spr, mot	0.003	823	0.26	5.8	2916	0.5393	0.0015	14.672	0.044	2804.1	1.5	1.0
	88GRS398 Quartzite boulder, Sandy Lake												
28	1 Ab zr, clr	0.005	20	0.32	1.3	622	0.5754	0.0029	16.864	0.086	2925.2	3.0	-0.2
29	1 Ab zr, clr, flat, no incl	0.008	13	0.49	0.5	1448	0.5653	0.0024	16.488	0.065	2917.4	4.4	1.2
30	1 Ab zr, brn	0.006	35	0.57	1.1	1459	0.5721	0.0022	16.637	0.065	2912.5	2.2	-0.2
31	1 Ab zr, lpr, clr, incl	0.008	12	0.34	1.3	580	0.5685	0.0020	16.520	0.067	2911.3	2.8	0.4
32	1 Ab zr, spr, brn	0.015	20	0.21	1.5	1561	0.5713	0.0016	16.597	0.051	2911.0	2.0	-0.1
	88GRS408 Pebbly arkose, Sandy Lake												
33	1 Ab zr, clr, melt incl	0.015	22	0.42	0.5	5511	0.5933	0.0021	18.404	0.068	3016.7	1.4	0.6
34	1 Ab zr, clr, melt incl	0.015	9	0.58	0.6	1892	0.5767	0.0028	17.273	0.087	2960.2	2.2	1.0
35	1 Ab zr, lpr, pale brn, incl	0.005	30	0.64	3.9	320	0.5758	0.0024	16.943	0.082	2931.7	3.2	0.0
36	1 Ab zr, eq, pale brn	0.005	44	0.39	1.6	1084	0.5714	0.0023	16.577	0.071	2908.7	1.9	-0.2
37	1 Ab zr, clr, spr, flat, no incl	0.008	7	1.05	1.15	379.9	0.5559	0.0025	16.086	0.108	2904.7	6.3	2.3
38	1 Ab zr, brn, crk	0.0025	95	0.14	2.1	896	0.5676	0.0014	16.422	0.046	2904.2	1.9	0.3
	DD97-1 Diorite dike, Sandy Lake												
39	1 Ab zr, spr, pale brn	0.008	45	0.72	0.5	4395	0.5274	0.0022	13.758	0.060	2735.2	1.8	0.2
40	1 Ab zr, brn, mot	0.002	138	0.57	0.4	4519	0.5217	0.0014	13.588	0.040	2732.5	1.6	1.2
41	1 Ab zr, brn, mot	0.008	4	0.51	0.8	263	0.5270	0.0032	13.662	0.096	2724.9	5.0	-0.2
	88GRS501 Felsic tuff, Ellard Lake												
51	1 Ab zr, euh, pale brn, melt incl	0.004	31	0.97	0.3	2599	0.5265	0.0016	13.717	0.045	2733.2	2.3	0.3
52	1 Ab zr, euh, eq, pale brn, melt incl	0.004	35	1.01	0.3	3023	0.5287	0.0020	13.772	0.053	2732.8	2.3	-0.1
53	1 Ab zr, subrnd, eq, pink, melt incl	0.010	22	0.79	0.9	1544	0.5251	0.0016	13.672	0.044	2732.0	2.1	0.5
54	1 Ab zr, subrnd, eq, pink	0.004	27	0.79	0.5	1521	0.5256	0.0018	13.683	0.049	2731.9	1.9	0.4
	88GRS503 Granodiorite, North Kenyon fault zone												
47	1 Ab zr, pale brn	0.002	52	0.76	0.9	728	0.5252	0.0015	13.637	0.045	2727.5	2.1	0.3
48	1 Ab zr, pale brn, melt incl, crk	0.004	22	0.77	0.6	886	0.5262	0.0020	13.629	0.053	2723.5	2.7	-0.1
49	1 Ab zr, clr	0.0015	19	0.03	1.4	143	0.5233	0.0034	13.539	0.112	2721.8	7.4	0.4
50	1 Ab zr, clr, crk	0.002	29	0.90	0.5	757	0.5235	0.0023	13.534	0.068	2720.4	4.0	0.3

NOTES: [a] Th/U calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age assuming concordance. [b] PbCom, common lead, assuming all have blank isotopic composition.
[c] %Disc, percent discordance for the given $^{207}Pb/^{206}Pb$ age. Decay constants are *from* Jaffey et al. (1971). Abbreviations: Ab, abraded; zr, zircon grain; euh, euhedral; eq, equant; spr, short prismatic; lpr, long prismatic; frag, fragment; clr, colourless; brn, brownish; mot, mottled (variable colour); crk, cracked; subrnd, subrounded; wrnd, well rounded; incl, inclusions.

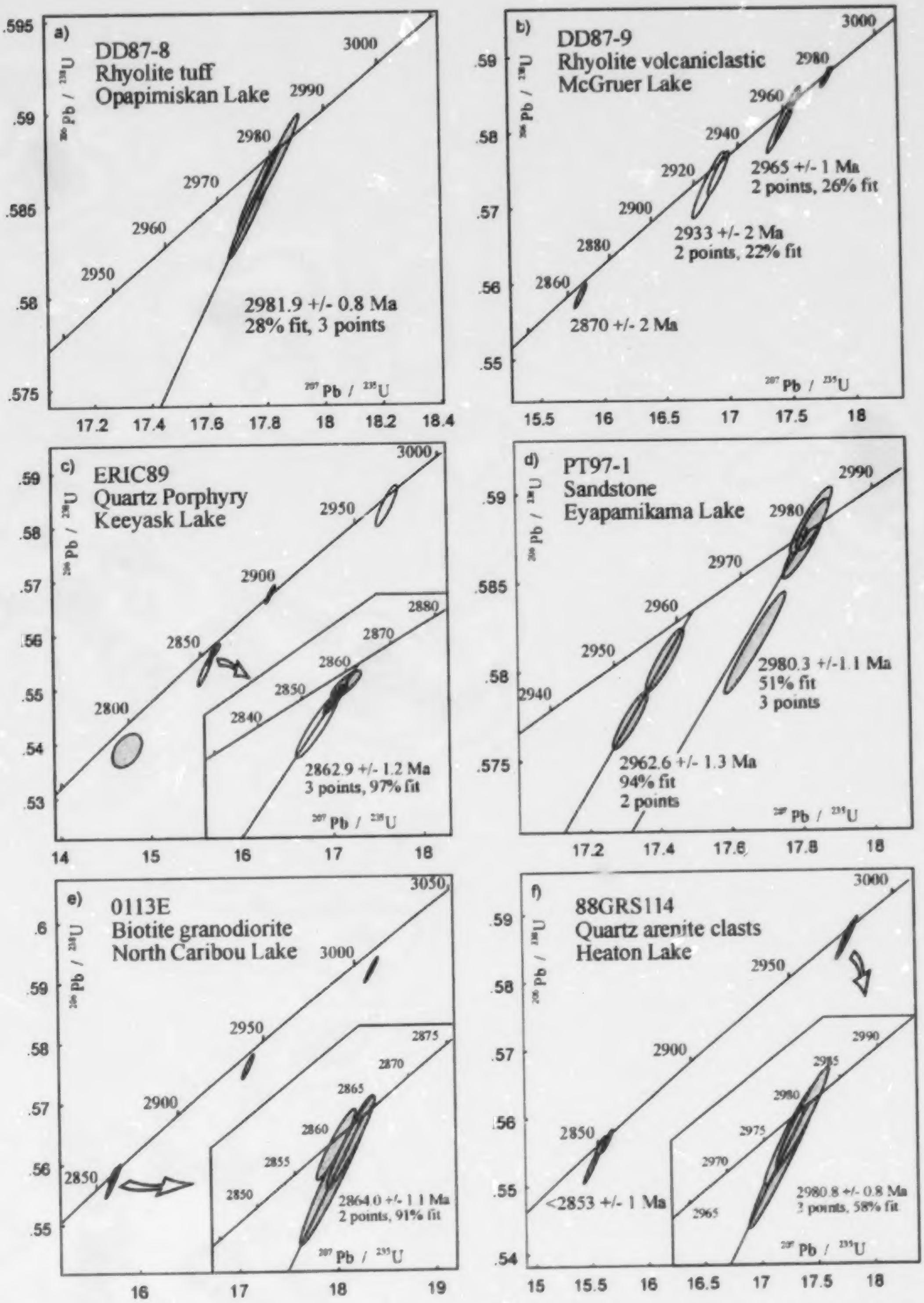

Figure 18.2. Concordia diagrams showing U/Pb analyses for zircon from samples taken in and near the North Caribou greenstone belt.

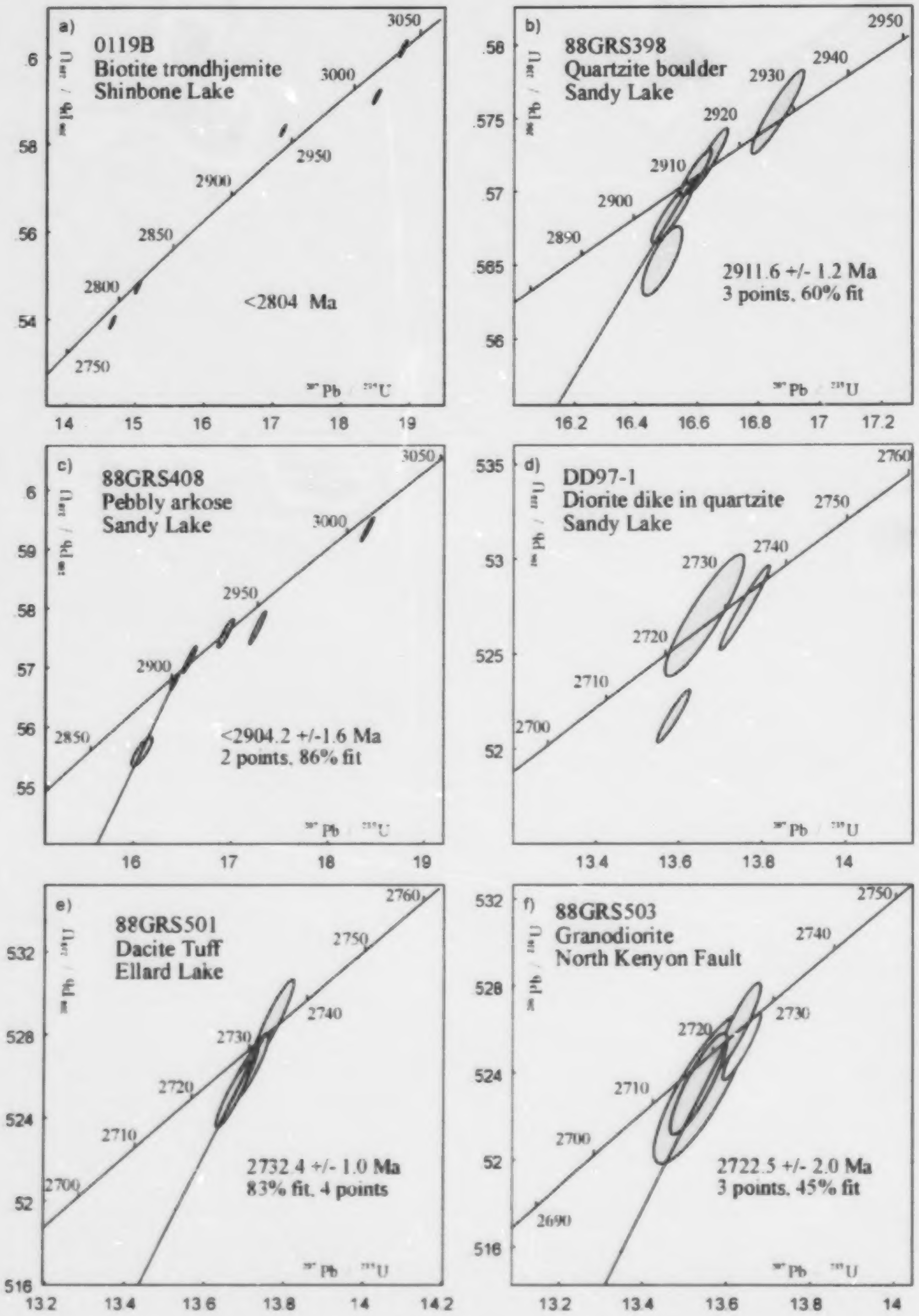

Figure 18.3. Concordia diagrams showing U/Pb analyses for zircon from samples taken (a) near the Windigo belt; (b, c, d) in eastern Sandy Lake belt; (e) in Ellard Lake belt; and (f) from Yelling Lake.

DD87-9 McGruer Lake Rhyolite (Figure 18.2b)

Zircon was moderately abundant in this sample. The population consists of short to long prismatic crystals with multifacetted tips. Most of them are cracked and altered.

Analyses of 3 single zircons were given in a previous report (Davis 1989). These have been recalculated and are given on Figure 18.2b (open ellipses) for comparison with 3 new single-grain analyses. All data are near-concordant. The youngest data point gives an age of 2870 ± 2 Ma. The oldest point gives 2980 ± 2 Ma, while the remaining data cluster into 2 pairs of points at 2965 ± 1 Ma and 2933 ± 2 Ma. The rhyolite clearly has a complex zircon population that is dominated by inheritance or xenocrysts. The age of eruption must be equal to or younger than the youngest datum, 2870 ± 2 Ma.

ERIC89 Keeyask Lake Quartz Porphyry (Figure 18.2c)

The sample was a hand specimen weighing about 2 kg. It yielded only a small amount of zircon, which is mostly zoned and altered. The main population consists of brown, short and long prismatic crystals with multifacetted tips.

Analyses of 2 single zircons were given in a previous report (Davis and Moore 1991). These have been recalculated and are given on Figure 18.3c (open ellipses) for comparison with 4 new analyses. A previously analyzed colourless zircon gave an age of 2975 ± 3 Ma (Davis and Moore 1991) and is clearly xenocrystic. Data from 3 brown grains, representing the main population, cluster near concordia and define an average ^{207}Pb/^{206}Pb age of 2862.9 ± 1.2 Ma. A zoned and cracked brown zircon was also analyzed, but the analysis contains a large proportion of common lead. This analysis indicates a younger age of about 2811 ± 18 Ma or slightly older. Because of the poor quality of this grain and uncertainty in the source of the common lead, the age of the unaltered brown zircons, 2863 ± 1.6 Ma, is probably the best estimate for crystallization of the main zircon population.

PT97-1 Eyapamikama Lake Sandstone (Figure 18.2d)

This sample yielded a small amount of pink to brownish zircon. The grains are mostly stubby, multifacetted and vary from euhedral to well rounded. Most grains are cracked and altered.

Analyses of 6 single zircons gave data points that group into 2 age clusters. Three of the data points are within error of 2980.3 ± 1.1 Ma, while a fourth is slightly older. The 2 youngest data points agree in ^{207}Pb/^{206}Pb age at 2962.6 ± 1.3 Ma. This is an older age limit on deposition of the sandstone.

0113E North Caribou Lake Granodiorite (Figure 18.2e)

Abundant zircon was recovered from this sample. Two populations appear to be present. One consists of colourless to pinkish short-prismatic, multifacetted crystals that vary from euhedral to rounded. The other is mostly long-prismatic brownish subrounded zircon that is generally highly cracked and altered. Some colourless fresh zircon grains appear to have altered cores.

This sample contains inheritance or xenocrysts as shown by ages of 3017 ± 1 Ma and 2947 ± 2 Ma from single brownish grains. Two euhedral colourless grains agree in age at 2864 ± 1 Ma. A brown fragment is slightly younger at 2861 ± 1.5 Ma. Although the zircon population is complex, the best estimate for the age of crystallization of the pluton is 2864 ± 1.1 Ma. The brown fragment may have been slightly affected by magmatic events at approximately 2.7 Ga.

88GRS114 Quartz Arenite Clasts, Heaton Lake (Figure 18.2f)

This sample yielded abundant zircon. The zircon population appears diverse, with subrounded to well-rounded grains of variable colour and morphology. Some zircons appear to have cores.

Six single zircons were analyzed. Three brownish grains produced data that overlap on concordia with an average age of 2980.8 ± 0.8 Ma. Three colourless grains are also clustered. The two youngest overlap in age at 2853 ± 1 Ma and one is slightly older. The age of the youngest zircons is an older limit on deposition of the quartz arenite.

0119B Shinbone Lake Trondhjemite (Figure 18.3a)

This sample yielded only a small amount of generally altered zircon. Most of the grains are long prismatic. A few equant multifacetted ones are also present.

Analyses of 5 single zircons gives a wide range of ages from 3037 ± 2 Ma to 2804 ± 2 Ma. Probably all of the zircons are xenocrysts or affected by inheritance. The youngest age is an older limit on crystallization of the pluton, which was probably emplaced through Mesoarchean crust during the period of magmatism at 2.7 Ga.

88GRS398 Quartzite Boulder, Sandy Lake (Figure 18.3b)

The sample yielded abundant zircon, mostly as pale brown, euhedral, short to long prismatic crystals with multifacetted tips. The population looks fairly uniform.

All 5 data points give ages that are near each other. The oldest is 2925 ± 3 Ma and the 3 youngest are within error at 2911.6 ± 1.2 Ma. This is an older age limit on deposition of the quartzite in the boulder and probably represents the age of the principal source.

88GRS408 Pebbly Arkose, Sandy Lake (Figure 18.3c)

Zircon was abundant in this sample. Most grains are brownish, euhedral, stubby to elongate, multifacetted crystals. Cores can be seen in some grains.

Six single zircons were analyzed and give a range of ages. The oldest age is 3017 ± 1 Ma. The 2 youngest agree in $^{207}Pb/^{206}Pb$ age at 2904 ± 2 Ma. However, 1 data point is discordant, so this agreement may be fortuitous. In any case, this age is an older limit on deposition of the metasediment.

DD97-1 Diorite Dike in Quartzite, Sandy Lake (Figure 18.3d)

The sample yielded abundant zircon as short to long prismatic, multifacetted crystals. Most of the zircon is highly cracked and altered.

Despite the high yield in zircon, it was difficult to recover fresh grains for analysis. Three single grains give ages that scatter between 2735 ± 2 Ma and 2725 ± 5 Ma, probably reflecting inheritance. The younger age is an older limit on crystallization of the dike, which was clearly emplaced during the late period of magmatism at approximately 2.7 Ga.

88GRS501 Ellard Lake Dacite Tuff (Figure 18.3e)

Very little zircon was recovered from this sample, but many of the grains are fresh. The population consists of slightly brownish, equant to stubby multifacetted crystals. The grains vary from euhedral to subrounded.

Analysis of 2 euhedral and 2 subrounded single zircons produced near concordant data points with overlapping ages. The average age of the cluster is 2732.4 ± 1.0 Ma. This is likely to be the age of eruption of the tuff.

88GRS503 North Kenyon Fault Zone Granodiorite (Figure 18.3f)

This sample yielded a very small amount of zircon. The population consists of brownish, zoned long and short prismatic crystals with multifacetted tips.

Four single zircons varying from brownish to colourless were analyzed and gave concordant data points. Three of the data points overlap within error and define an average age of 2722.5 ± 2.0 Ma. The fourth (unfilled ellipse on Figure 18.3f) is a few million years older. The age of the 3 clustered data points is probably the age of crystallization of the pluton.

DISCUSSION

Sandstones from opposite ends of the North Caribou belt (PT97-1 and 88GRS114) both show a clustering of detrital zircon ages at 2980 Ma, the age of a rhyolite previously dated in the Agutua Arm assemblage (Davis and Moore 1991) at the northwest end of the belt. Similar aged inheritance is also evident in the McGruer Lake metavolcanic rocks and the Keeyask Lake porphyry. Therefore, rocks of this age probably represented a major component in the area during deposition. The absence of evidence for 2700 to 2750 Ma detrital zircons in the Eyapamikama assemblage, corresponding to the period of most intense magmatism in the Superior Province, suggests that deposition occurred before this period. The age of 2982 ± 1 Ma for the rhyolite tuff in the North Caribou indicates that this belt is probably correlative with the felsic metavolcanic rocks west of Eyapamikama Lake. These results show that the period of magmatism at 2980 Ma was of regional extent.

The age of 2864 Ma for the granodiorite at North Caribou Lake is broadly similar to the ages of other phases of the North Caribou batholith (2870 ± 2 Ma and 2851 ± 2 Ma, Davis and Moore 1991). This batholith is suggested to be late or syntectonic with respect to folding of the North Caribou greenstone belt. If so, this would indicate that deposition of the quartz arenite at Heaton Lake is close to the age of its youngest zircons at 2853 ± 1 Ma. Other evidence supports this age as being a time of major sedimentation and komatiite volcanism. The rhyolite at McGruer Lake is not older than 2870 ± 2 Ma and underlies the Eyapamikama metasedimentary assemblage. Therefore, this should also be an older age constraint on deposition of these sandstones. The Keeyask Lake porphyry apparently intrudes komatiite of the Keeyask assemblage. Its age, 2863 ± 1 Ma, which is comparable to ages in the North Caribou batholith, puts a minimum time constraint on development of the Keeyask and Eyapamikama assemblages.

Youngest zircons from quartzites in the Sandy Lake belt at 2912 ± 1 Ma and 2904 ± 2 Ma suggest, like the results from the North Caribou Lake area, that early quartz arenite sedimentation may have occurred during 2.8 to 2.9 Ga. The diorite dike within the quartz arenite sequence marks the much younger magmatic period that is more widely distributed outside of the Mesoarchean North Caribou terrane. Similar Neoarchean magmatism occurs for example in the nearby Muskrat Dam Lake belt to the north (Davis 1989), close to the peripheral limits of the North Caribou terrane.

The 2 units dated from the Ellard Lake area, north of the North Caribou terrane, show Neoarchean ages in the range of the main period of arc-associated magmatism in the Superior Province, and comparable to the diorite dike dated in eastern Sandy Lake.

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19. Project Unit 98-002. Intermediate to Felsic Plutons in the Red Lake Greenstone Belt: Relationship to Deformation and Gold Mineralization

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INTRODUCTION

This report summarizes preliminary observations and interpretations from the second year of a multi-year project conducted in conjunction with the Western Superior NATMAP program. The project was initiated to study gold mineralization and related hydrothermal alteration at a regional scale within the Red Lake greenstone belt. This year, some limited field work was focussed on granitoid rocks that intrude the greenstone belt.

The purpose of this work is to

- Characterize the granitoid intrusions within the greenstone belt by documenting their petrology, mineralogy and geochemical characteristics; structural characteristics; distribution and mineralogical features of contact metamorphic aureoles.
- Determine the relationship of the intrusions to deformation, metamorphism, alteration and gold mineralization.

BACKGROUND

Sanborn-Barrie et al. (2000) have recognized 2 main stages (D_1 and D_2) of regional, penetrative, ductile deformation in the greenstone belt. D_1 deformation is a north-striking foliation that is axial planar to F_1 folds, whereas D_2 deformation is an east- to southeast-striking foliation that overprints D_1 and is axial planar to D_2 folds that refold F_1 folds (Sanborn-Barrie et al. 2000).

D_2 is a complex deformation associated with upright folding and emplacement of granitoid batholiths at about 2720 Ma (Dome stock, McKenzie Island stock, Hammell Lake batholith). A third phase of granitoid emplacement is recognized in the Killala–Baird batholith at 2704 ±1.5 Ma (Corfu and Andrews 1987) and the Walsh Lake pluton (also known as the Cat Island pluton) at 2699 Ma (Noble 1989). Granitoid emplacement at 2720 and 2700 Ma corresponds with the "Uchian phase" of the Kenoran Orogeny (2713 to 2701 Ma, Stott et al. 1989) and the D_2 deformation event (M. Sanborn-Barrie, Geological Survey of Canada (GSC), personal communication, 2000). Distribution of granitoid rocks is illustrated in Figure 19.1.

Regional greenschist-facies metamorphism probably occurred during D_1 deformation (Menard and Pattison 1998). Metamorphic grade increases from greenschist facies in the middle of the greenstone belt to amphibolite facies at the margins of the belt. Metamorphic isograds are concentric to the margins of external granitoid batholiths (i.e., Killala–Baird batholith, Walsh Lake pluton, Hammell Lake batholith)

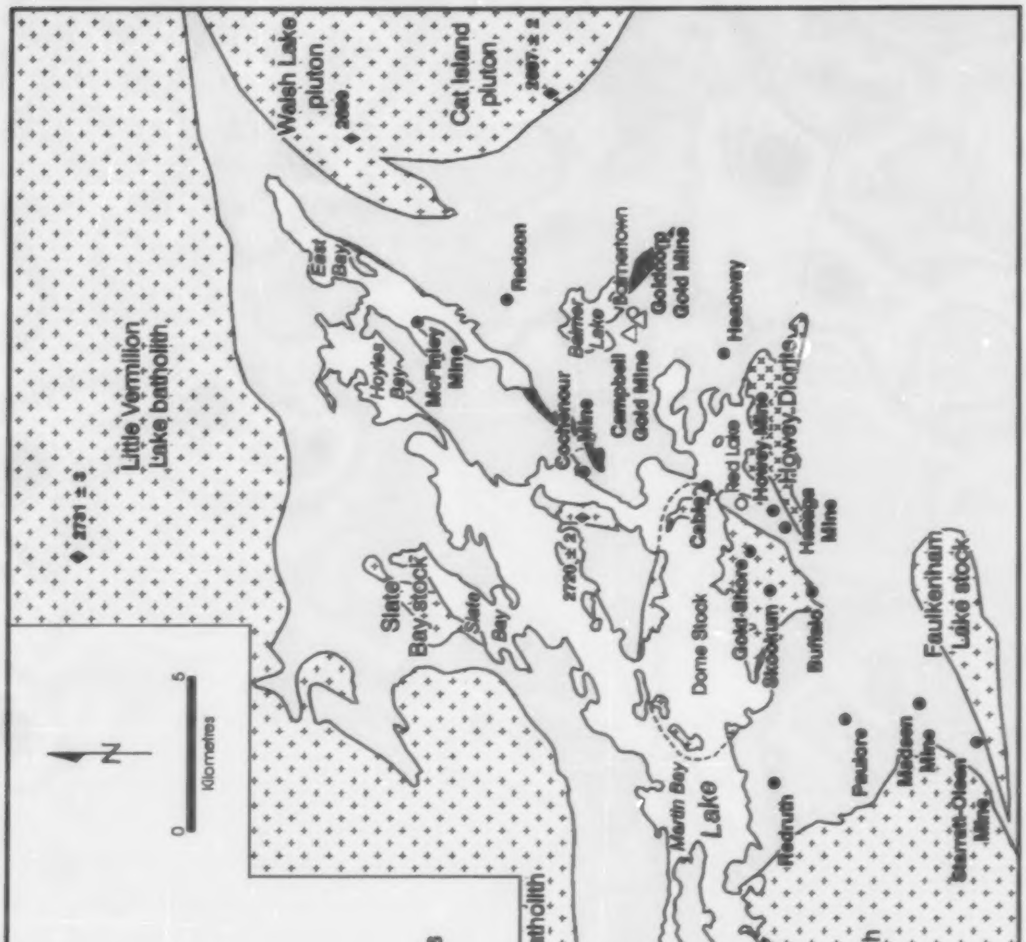
INTRUSIVE ROCKS
Granitic
Diorite
Ultramafic
SUPRACRUSTAL ASSEMBLAGES
Red Lake greenstone belt
Producing gold mine
Past-producing gold mine/properties
2734 ± 2 U-Pb zircon age (Ma)
N
0
5
Kilometres
Little Vermilion Lake batholith
2731 ± 3
Walsh Lake pluton
2699
Cat Island pluton
2697 ± 2
East Bay
Redcon
Bonnertown
Goldcorp Gold Mine
Balmer Lake
Headway
Hoyles Bay
McFinley Mine
Cochenour Mine
Campbell Gold Mine
Red Lake Mine
Howey Mine
Hasaga Mine
Howey Diorite
Slate Bay stock
Slate Bay
2720 ± 2
Cable
Dome Stock
Gold Shore
Skookum
Buffalo
Faulkenham Lake stock
Martin Bay
Red Lake
Redruth
Paulore
McMarmac Mine
Starratt-Olsen Mine
Hammell Lake batholith
2717 ± 2
2729 ± 1.5
Wolf Bay
Pipestone Bay
Trout Bay
Killala-Baird batholith
2704 ± 1.5
Douglas Lake pluton
2734 ± 2
50° 53' 30" N

Figure 19.1. Location, distribution and U/Pb zircon ages for intermediate to felsic plutons in the Red Lake greenstone belt.

consistent with contact metamorphism during batholith emplacement (Pirie 1982; Andrews et al. 1986; Damer 1997; Menard and Pattison 1998; Menard, Pettigrew and Spray 1999). The contact metamorphic aureole around the Dome stock is only partially preserved due to retrograde carbonate alteration that postdates the intrusion (Parker 2000). Three world-class gold deposits—the Campbell and Goldcorp mines and the past-producing Madsen Mine—are enclosed within contact metamorphosed amphibolite facies host rocks (Damer 1997; Dubé et al. 2000; Andrews et al. 1986).

GRANITOID INTRUSIONS

First Generation Intrusions

The Douglas Lake pluton and the Little Vermilion Lake batholith are 2 large intrusions—external to the greenstone belt—located at the west end of the greenstone belt and along the northeast margin of the belt, respectively (*see* Figure 19.1). Menard and Pattison (1998) correlated D_1 deformationwith the intrusion of the Douglas Lake pluton and the Little Vermilion Lake batholith at 2734 ± 2 Ma (Corfu and Stone 1998) and 2731 ± 3 Ma (Corfu and Andrews 1987), respectively.

The Douglas Lake pluton is a composite intrusion that has been mapped at a regional scale (Stone 1998) as biotite tonalite to granodiorite containing distinct books of biotite. Riley (1976) detail mapped phases of diorite, syenodiorite, and monzonite along the west margin of the intrusion. A large rafted segment of amphibolitized mafic metavolcanic rocks has been mapped south of Douglas Lake (Riley 1976). The intrusion hosts several occurrences of molybdenum, copper and sulphide minerals at Hatchet Lake and a few gold-bearing quartz veins along its west contact with metavolcanic rocks (Riley 1976). The intrusion is transected by a major, regional, west-northwest-striking deformation zone that is a prominent linear feature on aeromagnetic maps (Ontario Geological Survey 1998). Riley (1976) recognized quartz veins, molybdenum mineralization and mylonitic rocks along this structure. Supracrustal rocks are metamorphosed to lower amphibolite facies along the margin of the pluton and contain abundant hornblende, garnet, staurolite, andalusite and cordierite.

The Little Vermilion Lake batholith is a large, irregular, composite intrusion that has been regionally mapped by Stone (1998) as hornblende tonalite to granodiorite. Pirie and Sawitzky (1977) mapped in detail the southern margin of the intrusion as biotite-hornblende trondhjemite, granodiorite and syenodiorite with potassium feldspar megacrystic phases; dioritic and gabbroic phases; and abundant mafic xenoliths. Stone (1998) and Pirie and Sawitzky (1977) noted that the intrusion is weakly foliated. Supracrustal rocks at the margin of the batholith have been metamorphosed to lower amphibolite facies up to 1.6 km away from the batholith contact (Pirie and Sawitzky 1977). The metamorphosed rocks are deformed and consist of hornblende schist, biotite-hornblende schist and migmatite (Pirie and Sawitzky 1977). Mineral occurrences have not been documented in the Little Vermilion Lake batholith.

Second Generation Intrusions

These plutons consist of intrusions located within the greenstone belt such as the Dome stock, McKenzie stock and Howey "diorite" and the Hammell Lake batholith, which is a large external batholith (*see* Figure19.1). The Dome stock, McKenzie stock and Hammell Lake batholith were emplaced at about 2720 Ma and are interpreted to be coeval with D_2 which was a complex deformation event associated with upright folding (Sanborn-Barrie et al. 2000; Menard and Pattison 1998).

INTERNAL INTRUSIONS

Dome Stock

The Dome stock is approximately located in the middle of the Red Lake greenstone belt. The stock has a U/Pb zircon age of 2718 ± 1 Ma (Corfu and Andrews 1987) and is interpreted to have been emplaced during D_2 (syntectonic) by Sanborn-Barrie et al. (2001). However, Lavigne Jr. et al. (1986) suggested that the stock was overprinted by late deformation and was emplaced before deformation.

The Dome stock dominantly consists of massive, pink to gray, medium-grained hornblende-biotite granodiorite. The northwest margin of the stock consists of a dark gray, equigranular to pyroxene porphyritic diorite to monzogabbro that is intruded by the granodiorite (Ferguson 1965; Riley 1978b). The pyroxene diorite phase is identical to the pyroxene porphyritic diorite of the Red Crest stock in Todd Township (Riley 1978a) and the Altura stock in Fairlie Township (Riley 1978b). The Red Crest stock has a U/Pb zircon age of 2729 ± 1.5 Ma (Corfu and Andrews 1987) and may be coeval with this mafic phase of the Dome stock.

The Dome stock is variably altered and deformed and hosts several gold occurrences and prospects (i.e., Cable prospect on Whitehorse Island) as well as 2 past-producing gold mines (i.e., Red Lake Gold Shore Mine and the Buffalo Mine). A large portion of the stock is moderately to intensely iron carbonatized, sericitized and chloritic at Whitehorse Island; south of Hammell Channel on Red Lake; and in the vicinity of the Buffalo and Red Lake Gold Shore mines. Very strongly fractured and brecciated granodiorite is common in the southern half of the stock. North-striking faults and narrow mylonite zones were observed at Whitehorse Island. The metamorphic aureole around the stock has been overprinted by strong carbonate alteration in the surrounding supracrustal rocks (Parker 2000), however, metamorphosed and metasomatized chemical metasedimentary rocks are preserved along the northwest margin of the intrusion (Riley 1978b).

The Dome stock is intruded by numerous mafic dikes and hosts abundant xenoliths of the surrounding supracrustal rocks. The xenolith compositions include variolitic and amygdaloidal mafic metavolcanic rocks; chemical and clastic metasedimentary rocks; felsic metavolcanic rocks; gabbro and diorite; and ultramafic metavolcanic rocks.

The northwest margin of the Dome stock, mainly composed of augite diorite and gabbro, appears as a high magnetic anomaly on aeromagnetic maps and has magnetic susceptibilities that range between 11.3 and 45.6 (10^{-3} SI units). The southern, altered and deformed portion of the intrusion appears as a magnetic low on aeromagnetic maps (Ontario Geological Survey 1998) with magnetic susceptibilities ranging from 0.05 to 0.32 at Hammell Channel and from 15 to 20.1 at Forestry Point. The low magnetic susceptibilities at Hammell Channel may be due to intense alteration of the granodiorite which appears to have destroyed primary ferromagnesian minerals.

McKenzie Stock

The McKenzie stock has a U/Pb zircon age at 2720 ± 2 Ma (Corfu and Andrews 1987) and is probably related to the Dome stock. The McKenzie stock is a fine- to medium-grained, strongly iron carbonatized quartz diorite to granodiorite with low magnetic susceptibilities that range from 0.05 to 0.10. The stock hosts the past-producing Golden Eagle and McKenzie Island gold mines. The altered granodiorite appears to be enclosed within an augite diorite porphyritic phase that is interpreted (Ferguson 1965) to be coeval with the granodiorite. However, the “augite diorite” phase is actually a coarse-grained gabbroic rock containing large, abundant, acicular and euhedral feldspar megacrysts of possible labradorite. This gabbroic rock is not the same unit that is located along the northwest margin of the Dome stock. The gabbroic rock is extremely fresh, unaltered and undeformed and appears to be a late intrusion emplaced within the altered granodiorite. An ultramafic pyroxenite, which is also extremely fresh, unaltered and undeformed, appears to be a phase of the gabbro (Ferguson 1965). The gabbro has magnetic susceptibilities that range from 7.83 to 17.4.

Corfu and Andrews (1987) obtained a U/Pb titanite age of 2705 ± 8 Ma from an undeformed and unaltered gabbroic dike containing acicular feldspar phenocrysts at the Rowan Lake gold mine in Todd Township. This dike transects a gold-bearing deformation zone at the Rowan Mine. It is speculated that the unaltered gabbro at McKenzie Island may be of similar age to the dike at the Rowan Mine.

Howey "Diorite"

The Howey "diorite" is a very intensely deformed and altered intrusion. The intrusion includes the following phases: feldspar and quartz porphyries, aplite, quartz diorite, diorite and mafic amphibole and pyroxene diorite (Atkinson 1993; Pirie and Grant 1978; Pirie and Kita 1979). However, the rocks are so intensely altered in some locations (i.e., Chukuni River area) that the protolith is questionable and may actually be a metavolcanic or metasedimentary rock. The intrusion is carbonatized, intensely chloritized and contains magnetite veins; numerous pyrite, pyrrhotite and chalcopyrite occurrences; as well as gold-bearing quartz veins and a small cobalt occurrence. The metamorphic aureole around the Howey "diorite" has been obliterated by alteration and deformation. The Howey "diorite" has never had geochronological analyses, but is speculated to be the same age as the Dome stock (i.e., 2720 Ma). Both intrusions share similar styles of deformation (i.e., mylonitic zones, brecciation and intense fracturing) and alteration.

EXTERNAL INTRUSIONS

Hammell Lake Batholith

The Hammell Lake batholith is located along the north margin of the Red Lake greenstone belt and has a U/Pb zircon age of 2717 ± 2 Ma (McMaster 1987). This intrusion has been regionally mapped (Stone 1998) as potassium feldspar megacrystic granodiorite and as a biotite-hornblende trondhjemite along its southern margin (Riley 1975, 1978b). The batholith is associated with a small, irregular intrusion of anorthositic gabbro at the southeast end of Hammell Lake in Fairlie Township (Riley 1978b). Rocks are metamorphosed and metasomatized along the margin of the batholith. Riley (1970) mapped metasomatized marble units replaced by coarse diopside along the south margin of the batholith. Diopside skarn interlayered with pyrrhotite-rich chert, on the northeast side of Pipestone Bay, is reported by Riley (1970) to be 200 feet thick. The batholith is not known to host any mineral occurrences.

Third Generation Intrusions

The Killala–Baird batholith, Walsh Lake pluton and Cat Island pluton (*see* Figure 19.1) are 3 large intrusions with U/Pb zircon ages of 2705 ± 1.5 Ma (Corfu and Andrews 1987), 2699 Ma (Noble 1989) and 2697 ± 2 Ma (T. Skulski, GSC, personal communication, 2000). These intrusions are the last phase of significant felsic magmatism that affected the Red Lake greenstone belt. These are multi-phase intrusions that are spatially associated with the largest gold-producing mines in the greenstone belt, such as the past-producing Cochenour and Madsen mines and the currently producing Campbell and Goldcorp mines. In fact, the Campbell and Goldcorp mines occur within the metamorphic aureole of the Walsh Lake and Cat Island plutons, whereas the Madsen Mine occurs within the metamorphic aureole of the Killala–Baird batholith (Parker 2000).

KILLALA–BAIRD BATHOLITH

The outer margin of the Killala–Baird batholith consists of a quartz porphyritic granodiorite that is variably chloritic, sericitic, epidotized and hematized. The granodiorite commonly contains disseminated magnetite and has magnetic susceptibilities that range from 5.91 to 19.4. The marginal phase of the batholith stands out as a prominent magnetic high on aeromagnetic maps (Ontario Geological Survey 1998). The marginal phase also contains elliptical gabbroic and dioritic xenoliths, however, xenoliths of supracrustal rocks were not observed. The interior of the batholith contains several phases of dioritic to granodioritic rocks with variable textures and xenolith contents. However, all of the phases have relatively high magnetic susceptibilities.

Supracrustal rocks at the east margin of the batholith are intensely deformed and dip shallowly (20 to 30°) away from the intrusion. Gravity data (Gupta and Wadge 1978) indicates that the batholith plunges shallowly to the east beneath the supracrustal rocks (V. Wall, Taylor Wall and Associates, personal communication, 2001). This was confirmed by recent diamond drilling by Placer Dome Inc. in the vicinity of the Madsen Mine. The Killala–Baird batholith was intersected earlier than expected in diamond-drill holes that were collared about 1 km away from the mapped contact (R. Landry, Placer Dome Inc., personal communication, 2001). The batholith that was intersected in diamond-drill core is deformed with a strong tectonic fabric. The shallow plunge of the intrusion may explain why its metamorphic aureole extends almost 2 km or more from the margin of the batholith. Parker (2000) also documented a significant zone of calc-silicate mineral assemblages in previously carbonatized and altered mafic and ultramafic metavolcanic rocks along the entire margin of the batholith. The calc-silicate assemblage consists of diopside-calcite ± tourmaline ± garnet that is associated with gold mineralization at the Madsen Mine. The prograde calc-silicate assemblage is replaced and overprinted by retrograde actinolite ± magnetite veins on complex fracture networks.

The calc-silicate assemblage and metamorphosed rocks at the margin of the batholith are deformed and transected by late granodiorite dikes associated with the batholith. Boudinaged diopside veins are commonly parallel or subparallel to the penetrative foliation. This relationship indicates that the intrusion of the batholith (at about 2705 ± 1.5 Ma (Corfu and Andrews 1987)) was progressive with initial metamorphism occurring during deformation, followed by the intrusion of late dikes with U/Pb titanite ages of about 2699 ± 4 Ma (Corfu and Andrews 1987; T. Skulski, GSC, personal communication, 2000). There are also many localities along the margin of the batholith where the calc-silicate rocks are undeformed indicating that deformation was heterogeneous.

At the Madsen Mine, andalusite porphyroblasts in aluminous biotite alteration zones have crystallized along a S_1 foliation that is crenulated by a S_2 foliation. Porphyroblastic garnet and staurolite has crystallized along the S_2 foliation, but also overprints the foliation. However, skarn and amphibole veins associated with the Killala–Baird batholith overprint the metamorphic minerals and are variably deformed by the S_2 foliation. An alternative interpretation is that D_1, D_2 and metamorphism are broadly coeval so that D_1 and D_2 coincide with a single, but progressive, contact metamorphic and metasomatic event related to the Killala–Baird batholith. Foliation parallel andalusite, garnet and staurolite may indicate that peak metamorphism occurred during D_1 and early-D_2 deformation, while posttectonic garnets indicate that peak metamorphism outlasted D_1 and D_2 deformation. The above observations suggest that localized deformation occurred along the margin of the batholith during its emplacement at about 2705 ± 1.5 Ma (Corfu and Andrews 1987).

The Faulkenham Lake stock, located south of the Killala–Baird batholith (*see* Figure 19.1), is interpreted to be coeval with the batholith. The stock is dominantly composed of granodiorite intruded by late gabbro dikes and has a gneissic core composed dominantly of felsic metavolcanic rocks. Therefore, the stock may actually be a sill-like body. The stock is strongly deformed and altered in exposures near Staratt–Olsen.

WALSH LAKE AND CAT ISLAND PLUTONS

The outer margin of the Walsh Lake pluton consists of a wide zone of variably deformed, metamorphosed mafic metavolcanic rocks intruded by a complex network of granodiorite dikes associated with the pluton. The metamorphosed rocks also contain abundant calc-silicate mineral assemblages similar to those at the margin of the Killala–Baird batholith. These observations indicate that the intrusion of the Walsh Lake pluton (at about 2699 Ma (Noble 1989)) was also progressive with initial metamorphism occurring during deformation followed by the intrusion of late dikes, which is remarkably similar to relationships along the margin of the Killala–Baird batholith. The metamorphic aureole extends outward from the pluton for several kilometres and can be attributed to the shallow west plunge of the pluton below the supracrustal rocks as interpreted from gravity data (Gupta and Wadge 1978; V. Wall, Taylor Wall and Associates, personal communication, 2001).

The Walsh Lake pluton consists of a variety of phases including potassium feldspar megacrystic granite, tectonically foliated diorite and granodiorite. These rocks have relatively high magnetic susceptibilities that range from about 12 to 46.3. These data are consistent with aeromagnetic data (Ontario Geological Survey 1998) that shows a prominent magnetic high associated with the Cat Island pluton and part of the Walsh Lake pluton. However, the north lobe of the Walsh Lake pluton is a strong magnetic low (Ontario Geological Survey 1998). The Cat Island pluton is similar in composition to the Walsh Lake pluton and consists of biotite granodiorite to granite and potassium feldspar megacrystic granodiorite to granite that has a U/Pb zircon age of 2697 ± 2 Ma (T. Skulski, GSC, personal communication, 2000). The Cat Island pluton was not visited during this field season.

The relative timing of metamorphism and deformation in the metamorphic aureoles of the Walsh Lake and Cat Island plutons is constrained by regional syntectonic and posttectonic textures in aluminous biotite alteration zones associated with the Campbell and Goldcorp gold mines. Garnet porphyroblasts grew along the southeast-striking "mine trend" (S_2), but also overprint this foliation. Damer (1997) documented the same relationships for the majority of metamorphic minerals (i.e., andalusite, chloritoid, staurolite, cummingtonite) at the Goldcorp Mine. Menard and Pattison (1998) noted that the cores of some garnets overprint an early S_1 foliation, whereas garnet rims overprint the S_2 foliation. These relationships indicate that syntectonic metamorphic minerals crystallized during the development of penetrative fabrics, whereas posttectonic metamorphic minerals probably crystallized at the end of deformation. Posttectonic metamorphic minerals may also indicate that metamorphism outlasted deformation. Damer (1997) and Menard and Pattison (1998) identified distinct inclusions of gold and sulphide minerals in the cores of garnet porphyroblasts which suggests that garnet growth occurred during the mineralizing event. Damer (1997) suggested that the metamorphic minerals were formed during contact metamorphism imposed by the Walsh Lake pluton which suggests that some D_2 deformation (or a D_3 deformation) was synchronous with the metamorphic event.

SUMMARY

Recent work by Beakhouse (2000, 2001), on felsic intrusions in the Hemlo greenstone belt, has shown that there may be a connection between late, oxidized, magnetite-bearing felsic intrusions and gold mineralization. Hattori (1987) also showed that felsic intrusions spatially and temporally associated with Archean gold deposits in the Superior Province are commonly magnetic with high magnetite contents.

Preliminary work during this study has shown that several late intrusions in the Red Lake greenstone belt, such as the Killala–Baird batholith, the Walsh Lake and Cat Island plutons and parts of the Dome stock are moderately to strongly magnetic with relatively high magnetic susceptibilities. These intrusions are commonly spatially associated with significant gold mineralization.

The relative timing of metamorphism and deformation in the metamorphic aureoles of the Killala–Baird batholith, Walsh Lake and Cat Island plutons is constrained by syntectonic and posttectonic textures, such as metamorphic minerals that have grown along foliations, but also overprint the foliation. These relationships indicate that syntectonic metamorphic minerals crystallized during the development of penetrative fabrics, whereas posttectonic metamorphic minerals probably crystallized at the end of deformation or outlasted deformation. Damer (1997) suggested that the metamorphic minerals were formed during contact metamorphism imposed by the Walsh Lake pluton, which suggests that some D_2 deformation (or a D_3 deformation) was synchronous with the metamorphic event. The same relationships can be observed at the margin of the Killala–Baird batholith.

More work must be done to characterize the intrusions and the intrusive history of the Red Lake greenstone belt, but preliminary studies show that there may be a link between late, oxidized, magnetite-bearing intrusions in the Red Lake greenstone belt and gold mineralization.

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20. Project Unit 01-06. Phoenix Bedrock Mapping Project: Geology of Proterozoic Mafic to Ultramafic Intrusions in the Beardmore Area

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INTRODUCTION

The Phoenix Bedrock Mapping Project is an economic development initiative financially supported by an Industry Canada (through FedNor) allocation to the Lake Nipigon Heritage Authority, and conducted by the Precambrian Geoscience Section of the Ontario Geological Survey. The objective of the project is to conduct bedrock mapping at 1:20 000 and 1:50 000 scale in a large area, east of Lake Nipigon and west of Beardmore, that was burnt during a major forest fire in 1999 (Figure 20.1). The fire has enhanced outcrop exposure in most of Kitto, Eva and Dorothea townships and parts of Summers and Sandra townships, providing an opportunity to collect new geoscience information. The Beardmore area has mineral resource potential for gold, volcanogenic massive sulphide mineralization and magmatic platinum group element (PGE) mineralization. The objective of this project is that this new information will generate interest in prospecting, mineral exploration and investment and create and/or maintain community-based jobs and opportunities for the Municipality of Greenstone and the surrounding area.

This portion of the Phoenix project evaluated 1) the economic potential of the Proterozoic ultramafic and mafic intrusions; and 2) the position of the Proterozoic intrusions within the tectonostratigraphic framework of the Proterozoic mid-continent rift.

Beardmore is located approximately 190 km northeast of Thunder Bay and east of Lake Nipigon. Access is provided by the Canadian National Railway (CNR), Highway 11, a series of logging roads extending north and south from Highway 580, and the shore of Lake Nipigon. Previous geological work on the intrusions was conducted by Mackasey (1975) and Shanks (1993) as part of 1:20 000 scale mapping of Dorothea and Sandra, and Eva and Summers townships, respectively. Kitto Township has never been mapped at 1:20 000 scale. Geological investigations of the intrusions were completed by Sutcliffe (1981, 1986) with 1:50 000 scale mapping in Kitto and southern Eva townships by Sutcliffe and Greenwood (1985). Mineral exploration and prospecting in the surrounding area was initially conducted mainly for iron ore in the 1900s, but expanded to gold in 1925 (Mason and White 1986). The rocks of the area have never been systematically explored for their platinum group element (PGE) potential. An ultramafic intrusion in Kitto Township, interpreted to be time equivalent (Proterozoic) to the ultramafic intrusions of the Leckie and Disraeli lakes area (Sutcliffe 1991), is currently being explored for PGE mineralization.

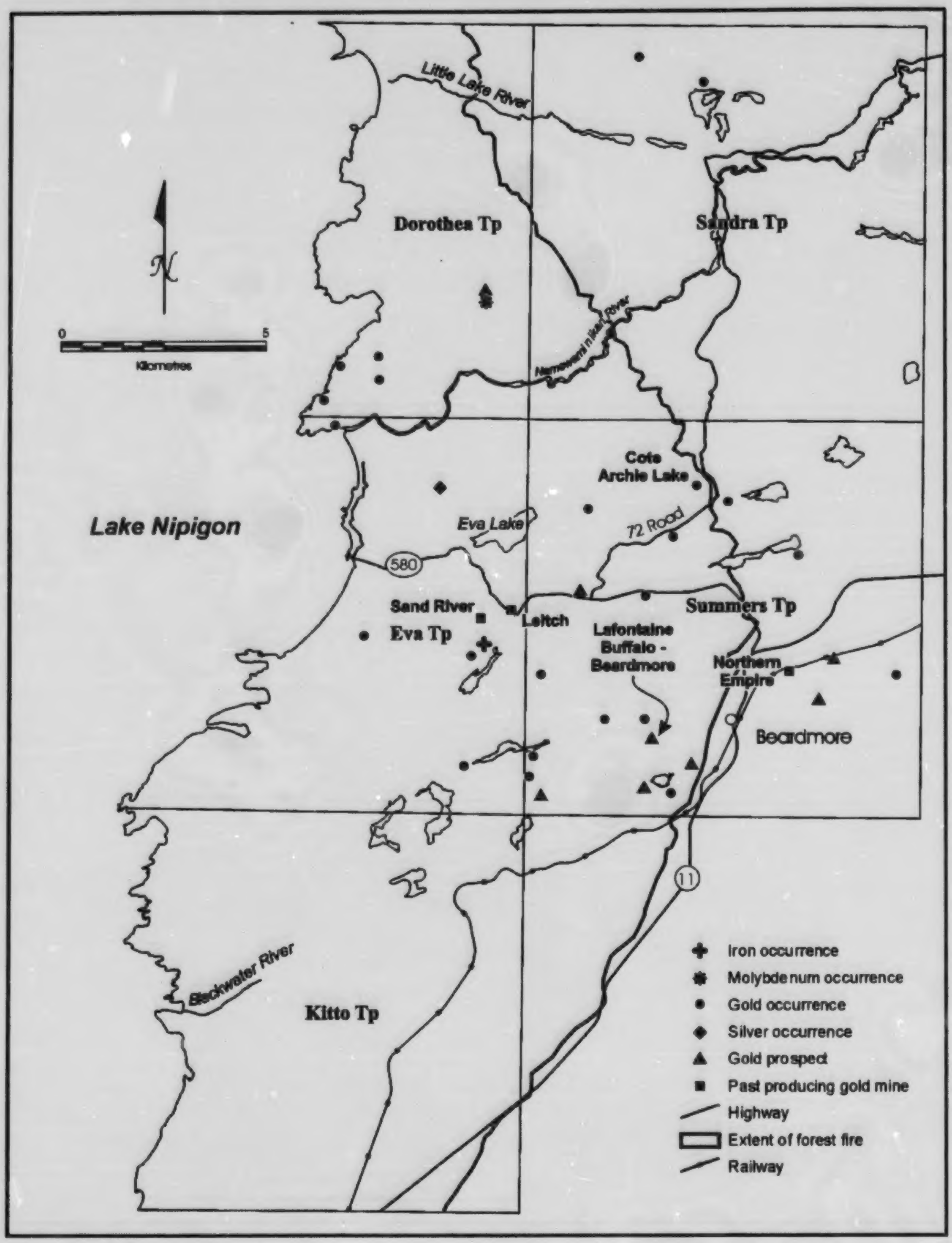
Little Lake River
Dorothea Tp
Sandra Tp
N
0
5
Kilometres
Namewaminikan River
Cote
Archie Lake
Lake Nipigon
Eva Lake
72 Road
580
Sand River
Leitch
Eva Tp
Summers Tp
Lafontaine
Buffalo -
Beardmore
Northern
Empire
Beardmore
11
Blackwater River
Kitto Tp
Iron occurrence
Molybdenum occurrence
Gold occurrence
Silver occurrence
Gold prospect
Past producing gold mine
Highway
Extent of forest fire
Railway

Figure 20.1. Mineral occurrences of the Beardmore area.

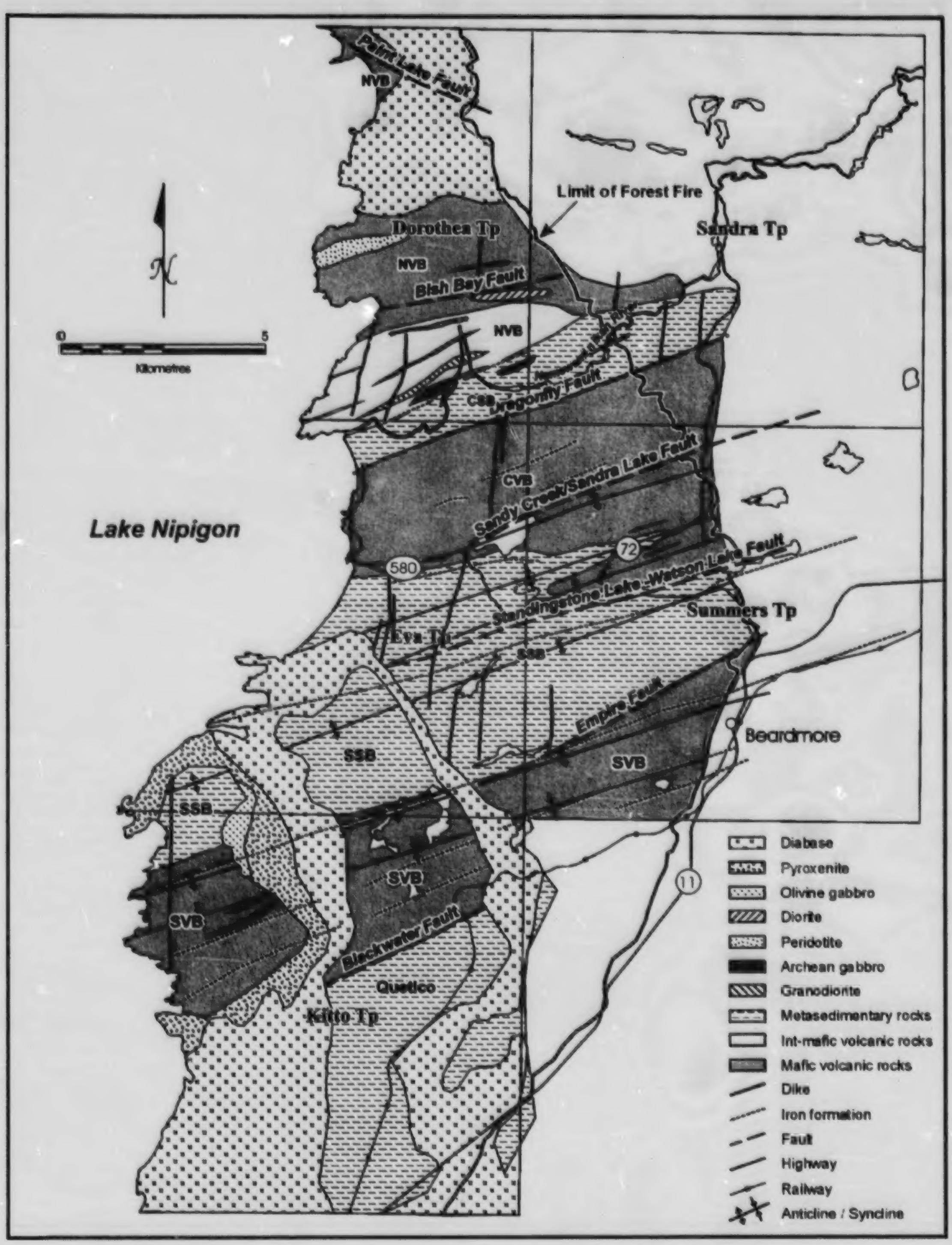
Paint Lake Fault
NVB
Limit of Forest Fire
Dorothea Tp
Sandra Tp
NVB
Bish Bay Fault
NVB
N
0
5
Kilometres
CSB
Dragonfly Fault
CVB
Sandy Creek/Sandra Lake Fault
Lake Nipigon
580
72
Standingstone Lake-Watson Lake Fault
Summers Tp
Eva Tp
SSB
Empire Fault
Beardmore
SSB
SVB
SSB
SVB
SVB
Blackwater Fault
Quetico
Kitto Tp
11
Diabase
Pyroxenite
Olivine gabbro
Diorite
Peridotite
Archean gabbro
Granodiorite
Metasedimentary rocks
Int-mafic volcanic rocks
Mafic volcanic rocks
Dike
Iron formation
Fault
Highway
Railway
Anticline / Syncline

Figure 20.2. Geology of Kitto, Eva, Dorothea, Summers and Sandra Townships. Abbreviations: CSB, Central Sedimentary sub-belt; CVB, Central Volcanic sub-belt; NVB, Northern Volcanic sub-belt; SSB, Southern Sedimentary sub-belt; SVB, Southern Volcanic sub-belt (all terms *from* Devaney and Williams 1989).

GENERAL GEOLOGY

The Phoenix project area is underlain by Archean metasedimentary and metavolcanic rocks of the Beardmore–Geraldton Belt (BGB), which forms the southern margin of the eastern Wabigoon Subprovince (Figure 20.2). The belt is bounded to the south by metasedimentary rocks of the Quetico Subprovince and to the north by metavolcanic rocks of the Onaman–Tashota greenstone belt. Metasedimentary rocks of the BGB consist of feldspathic wacke, lithic wacke, siltstone, lithic arenite, polymictic conglomerate, mudstone and/or argillite, and argillite-magnetite and jasper-hematite iron formations. Metavolcanic rocks of the belt are predominantly massive basaltic flows, pillowed flows, tuffs and lapilli tuffs with lesser amounts of intermediate flows, tuffs and tuff breccias. Interbedded with the flow units are a number of chert-magnetite iron formations. A series of thin, Archean gabbro sills, with chilled margins, intrude the supracrustal rocks. Thinly bedded feldspathic wacke, siltstone, argillite, and conglomerate of the Quetico Subprovince are exposed in the southeastern corner of the map area. The metamorphic grade varies from middle to upper greenschist facies in the north, to amphibolite facies in the southeastern portion of the metavolcanic unit and the Quetico Subprovince metasedimentary rocks. The rocks of the BGB have been interpreted to represent the collisional zone formed between the Wabigoon and Wawa subprovinces (Devaney and Williams 1989; Shanks 1993; Tomlinson et al. 1996).

A swarm of narrow, north-trending diabase dikes cut the metasedimentary and metavolcanic rocks of the BGB. A Proterozoic intrusion consisting of olivine pyroxenite and pyroxene peridotite forms a ring-shaped intrusive feature in western Kitto Township. Proterozoic diabase sills, at least 100 m thick, intrude all other units, with chilled upper contacts common in the southeastern part of the map area. Extensive Quaternary deposits form a nearly continuous cover along portions of the lakeshore and in the south-central part of the map area.

Diabase Dikes

A swarm of north-trending, fine- to medium-grained, massive to occasionally plagioclase porphyritic, 2 to 3 m wide diabase dikes cut the metasedimentary and metavolcanic units of the BGB. The dikes in the southern portion of the map area are more highly altered and metamorphosed and resemble the Archean gabbroic rocks that the dikes crosscut. These southern dikes are also distinguished by a high degree of wall rock alteration forming zones subparallel to contacts. Some dikes contain multiple chills with associated bands of fine epidote-filled vesicles suggesting that the same dike was the conduit for multiple pulses of magma. Dikes of the same swarm, located in Dorothea Township, are much less altered and generally lack the wall rock alteration zones resulting in an appearance similar to the Proterozoic sills. These north-trending dikes have been referred to as the Nipigon dike swarm, and, in some cases, have been interpreted to be feeders for the Nipigon sills (Osmani 1991). There are no radiometric ages reported, but similar north-trending dikes along the north shore of Lake Superior intrude the Osler Formation. Some of the more altered dikes may be part of the Marathon dike swarm (2170 Ma), a north- to northeast-trending dike swarm identified further to the north and east of the BGB (Osmani 1991).

Ultramafic Intrusion

An ultramafic unit intrudes metasedimentary and metavolcanic rocks of the BGB in Kitto and southwest Eva townships. This intrusion is one of a number of ultramafic intrusions that have been assumed to be Proterozoic in age (Sutcliffe 1991). Two of these intrusions in the Leckie and Disraeli lakes area, south of Lake Nipigon, are currently the focus of a PGE exploration program. The main body of the intrusion was initially mapped as a peridotite (Sutcliffe and Greenwood 1985), but appears to be crudely zoned, with a pyroxene peridotite outer zone and an olivine pyroxenite inner zone.

The pyroxene peridotite is medium grained, massive with a medium brown to dark brown weathered surface, occasional poikiolitic pyroxene grains and 1% fine-grained reddish brown biotite. The olivine pyroxenite is similar in appearance to the peridotite except for the presence of approximately 5% coarse-grained, subhedral pyroxene phenocrysts and irregular leucocratic patches with higher plagioclase content. Outcrop exposure is sparse, probably due to the extreme weathering of the pyroxenite, and internal and external contacts are not commonly observed. The contact between the pyroxenite and the diabase is exposed in only one location along the southern contact, in a streambed near Lake Nipigon. At that location, extreme weathering of the pyroxenite has resulted in the initial development of a regolith, but the relatively well-preserved overlying diabase is fine grained and appears to have a chill margin against the pyroxenite.

An olivine gabbro is located along the inner contact of the pyroxenite, in the area of the contact between a metasedimentary and a metavolcanic band within the BGB. The gabbro resembles the diabase, but has a higher olivine content and 5 to 10% dark brown to black biotite, resembling the matrix of the hybrid contacts of the diabase sills with the Quetico Subprovince metasediments (*see* "Diabase Sills"). A portion of the body is coarse grained with pinkish feldspar and small, irregular, possibly mariolitic cavities and may represent the granophyric phase of the ultramafic intrusion. However, the olivine gabbro and granophyre may be the uneroded upper portion of the diabase sill that originally had overlain the pyroxenite. The gabbro–metasedimentary rock contact is similar to the hybrid contact described for the Proterozoic diabase (*see* "Diabase Sills").

Diabase Sills

A series of undulating, generally flat-lying to shallow-dipping Proterozoic diabase sills intrude all other rock units in the area . The diabase sills are commonly composed of massive, medium- to fine-grained feldspar and pyroxene with trace to 5% fine-grained olivine and magnetite. Some locations have a coarse-grained diabase overlain by a medium-grained, magnetite porphyritic diabase with 5 to 10% medium-grained, subhedral magnetite. This sequence could be interpreted as an igneous fractionation trend. Although the magnetite porphyritic variety is common in all sills in the area, coarse-grained diabase is observed in only a few locations with some occurrences being irregular veins and pods. The irregular distribution of the coarse-grained phase may be interpreted to be due to a number of factors: mixing of different pulses of magma at different stages of fractionation; different degrees of fractionation in different portions within any one sill; late magmatic fluid; or fluids from assimilated supracrustal material. Alternatively, the irregular distribution may simply be due to a higher degree of weathering commonly associated with the coarse-grained phase and the lack of identifiable exposures.

Two styles of contacts, polygonal and hybrid, are observed in the area. Polygonal contacts consist of a polygonal jointed, aphanitic diabase with very fine-grained amphibole occurring along the joints. An observed vertical section through a basal chill zone has a 2 cm aphanitic zone and a gradual upward increase in grain size over a distance of up to 1.5 m. The hybrid contact consists of fine-grained diabase with up to 10% fine-grained black biotite containing either blocks or pebble-size xenoliths. The angular to subangular blocks are composed of fragments of metasediment, which, in one example, appears to have broken along bedding planes. The pebble-size xenoliths are subrounded to rounded and commonly composed of coarse-grained quartz and white to pinkish feldspar that resembles a granite to granodiorite intrusive rock. In one well-exposed area, there are pebble xenoliths and irregular-shaped quartz-rich xenoliths both with fine rims of biotite (Photo 20.1). The irregular xenoliths may be mariolitic cavities indicating a significant fluid and/or volatile phase in the magma. The presence of country rock xenoliths in a biotite-rich diabase matrix is indicative of the assimilation of the country rocks by the intruding diabase.

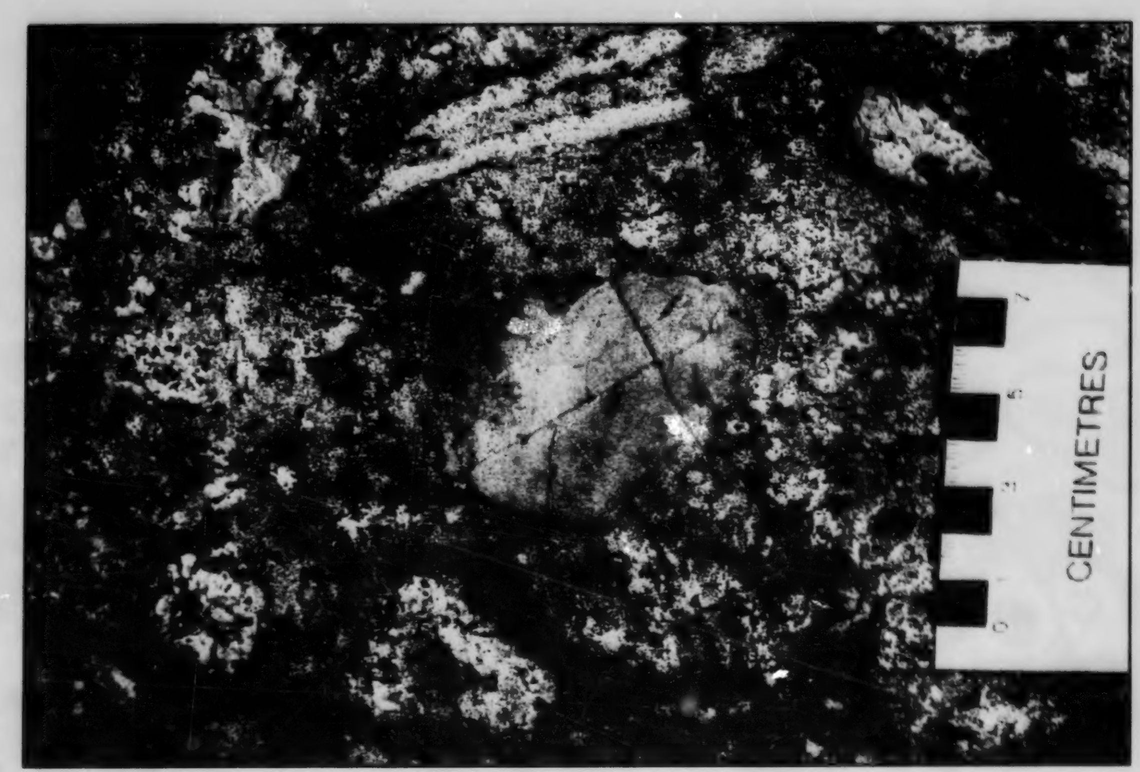

Photo 20.1. Pebble-sized xenoliths of assimilated (quartz and feldspar) and partially assimilated Quetico Subprovince metasedimentary rocks in chilled biotite-rich diabase, northeast Kitto Township.

Structural Geology

Jointing is common in both the diabase sills and pyroxenite and has been used in the past as indicators of the intrusion orientation. The diabase has both arcuate and linear joints. The arcuate joints, exposed in the face of the CNR ballast quarry in Kitto Township, can be traced from an approximately 30° dip at the bottom of the face to a 90° orientation. These joints are interpreted to be cooling fractures (Photo 20.2). There is one example of a series of arcuate joints outlining a possible flow tube in the north face of the quarry. Linear joints are late structures that transect the cooling fractures and appear to be related to regional structures. Jointing is common in the pyroxenite and the shallow dipping joints have been interpreted to be indicators of an original shallow dipping sills orientation of the pyroxenite intrusion. These joints could be cooling joints with a similar arcuate trace as those observed in the diabase, so the use of joints to predict the original orientation of the pyroxenite may not be valid.

Diabase sill thickness is difficult to determine as the upper and lower contacts are never observed in the same location. The thickness of the sill in the northeast portion of Kitto Township is at least 100 m, based on an observed basal contact and the height of the diabase hill. A second diabase sill, intersected at about 500 m depth in the shafts of the Leitch and Sand River gold mines, is about 185 m thick, and the surface sill may have originally been of the same thickness.

The diabase sill contacts that have been observed generally dip less than 30° in a variety of directions, but, in eastern Kitto Township, the contact dips to the east. Nearly flat-lying, outwardly dipping contact orientations do not fit the previously suggested cone sheet model for the diabase (Sutcliffe 1991), and the distribution of diabase may be a result of erosion as the sills generally form topographic highs.

Photo 20.2. Arcuate cooling fractures—joints with later linear joints—in the face of the CNR ballast quarry; note the light coloured alteration surrounding a fracture to the right of the person.

Although the pyroxenite forms a ring-shaped body, the orientation of the intrusion is not known due to the lack of definitive contact relationships. Possible orientations range from a near vertical circular dike to a shallow west-dipping sill. Controls on the location of the intrusions may be complex as it transects both a metasedimentary and metavolcanic contact within the BGB and the Wabigoon–Quetico subprovinces boundary and either or both contacts may have been important in localizing the intrusions.

Alteration and Mineralization

Strong to intense epidote and quartz-epidote alteration is commonly associated with the southern diabase dikes, forming 2 to 8 m wide zones of moderate to intense alteration subparallel to the dike contacts. These zones have the same intensity and width in both the metasedimentary and the metavolcanic rocks of the southern BGB, but are generally lacking in the northern areas. The main difference between the northern and southern portions of the BGB is a higher regional metamorphic grade that may indicate a connection with deeper crustal levels or some other source of fluids available in these rocks.

A hornfels zone is developed in the mafic metavolcanic rocks and iron formation in contact with the olivine gabbro. The result is a zone composed of alternating bands of magnetite-rich and magnetite-poor amphibole-rich silicate rock. The amphibole-rich bands are composed of an amphibole that weathers to a pale green to grey suggesting a tremolite composition, and contains lapilli- to block-sized fragments that are scoriaceous in appearance. The higher heat flow required to create the hornfels zone would be consistent with the interpretation of the olivine gabbro as a granophyre.

Alteration within the Proterozoic diabase is usually confined to joints and fractures commonly near the top of the sill, but also is observed in fractures in the centre of the sill. The joints may contain very coarse-grained to pegmatitic subhedral hornblende, hornblende-albite, hornblende-pinkish feldspar, or rarely magnetite, with hornblende-feldspar being the most common. Irregular pods of coarse- to very coarse-grained hornblende-feldspar are also observed in the diabase near the upper contacts. Aplite fracture-fillings are present in the CNR ballast quarry, and commonly have continuous to discontinuous bleached alteration rims up to 1 cm wide. The source of the fluid involved in the alteration within the diabase is not known, but initial X-ray diffraction analyses indicates the presence of pectolite and wollastonite, which may be a result of interaction between the diabase and limestones of the Sibley Group. Other possible sources of fluid may be late magmatic or other supracrustal rocks. The presence of country rock xenoliths, in a biotite-rich diabase matrix in contact with a variety of rock types, indicates that fluids may have been incorporated from a number of different sources.

The pyroxenite, cropping out along the east shore of Lake Nipigon, has a blocky or brick work appearance with serpentinized fractures. In some fractures, extreme weathering results in a central-fracture-filling of serpentine with subparallel bands of medium-grained magnetite, and total disintegration of the pyroxenite with development of a near regolith. This extreme weathering or total disintegration of the pyroxenite is probably the cause of the poor outcrop exposure for this unit. Other good examples of this style of weathering are located along a streambed that marks the southern contact of the pyroxenite with the diabase.

Mineralization within the diabase consists of trace amounts of disseminated pyrrhotite and pyrite and chalcopyrite in joints, close to the upper or lower contacts, and associated with the hornblende-feldspar joint-fillings. Good examples of this contact-related mineralization are present in the upper contact along the gas pipeline in southeast Kitto Township, and along the basal contact between the diabase and the pyroxenite in northeast Kitto Township. Trace, disseminated, fine- to very fine-grained pyrrhotite and pyrite is present in the diabase along the Little Lake River, northern Dorothea Township, near the location of a palladium anomaly reported by Mackasey (1975). The fine- to very fine-grained, disseminated pyrrhotite occurs in trace amounts as an accessory mineral phase in much of the diabase. Assays for all locations are pending.

TECTONOSTRATIGRAPHIC DISCUSSION

The Nipigon diabase sills are often considered to simply be a part of the Logan sills located to the south along Lake Superior (Sutcliffe 1991). However, olivine is present as a minor mineral phase in the diabase of the Nipigon sills, on both the eastern and western side of Lake Nipigon. This is in distinct contrast to the Logan sills closer to Lake Superior (J. Franklin and R. Middleton, personal communication, 2001). Olivine is most prominent in large bodies along Lake Superior , such as the Crystal Lake gabbro (Sutcliffe 1991), some of which host copper-nickel-PGE mineralization. The elevated olivine content in the Nipigon sills may also indicate a more primitive magma with a better chance of hosting PGE mineralization, but further investigation of these differences will be required. The difference in olivine contents also has implications with respect to the formation of the Nipigon and Logan sills and possible differences in magma generation due to different 1) magma sources, 2) depth of melting, and/or 3) degrees of modification before intrusion.

RECOMMENDATIONS

A radiometric age determination for the sills, and especially for the granophyric phase of the ultramafic intrusion, would aid in the formulation of a sequence of events for the intrusive units.

The pyroxenite has been described as being compositionally similar to the ultramafic intrusions at Seagull and Disraeli lakes, south of Lake Nipigon (Sutcliffe 1991). The Seagull and Disraeli intrusions host PGE mineralization in an upper horizon containing oxide minerals and a lower chalcopyrite, pyrrhotite-pentlandite, and minor chromite horizon hosted by lherzolite (East West Resources 2001). A basal contact zone of disseminated sulphide minerals was also intersected during diamond drilling. Further work is required to investigate the similarities between the intrusions, but the contact zones of the pyroxenite have not been extensively prospected.

The hornfels zone and the granophyre also have the potential to host a contact style of mineralization, as is evident from the degree of interaction between the two rock types. Extensive prospecting of this area has not been conducted.

The recognition of coarse-grained zones, pegmatitic joint-fillings, and hybrid contact zones indicate a previously unrecognized complexity in the diabase and a hybrid type of diabase possibly similar to gabbros hosting PGE mineralization in the Lac des Iles deposit. The best results to date have been hosted by diabase in the area of a major regional structure (e.g., Little Lake River palladium showing and the Paint Lake fault). The presence of PGE mineralization may be due to fluids released by reactivation of this structure (Middleton 2001) or the assimilation of pre-existing sulphide mineralization located along the structure, aiding in PGE precipitation. Areas of interest would be where other major regional structures intersect the diabase, zones close to areas of sulphide mineralization in the country rock, and any large zones of coarse- to very coarse-grained diabase indicative of a fluids resulting from diabase–country rock interaction.

Modelling of the magnetic data from the OGS airborne geophysical survey (OGS 1998) would be useful in determining the orientation of the Proterozoic diabase sills and possibly the ultramafic intrusion. Information on the orientation of the intrusions would be useful for directing exploration to depth along the contact of a dipping sill with a possible feeder dike, or confining work to more vertical targets. At the same time, this information may aid in developing a better understanding of the controls on the location of the ultramafic intrusion.

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21. Project Unit 01-06. Phoenix Bedrock Mapping Project: Geology of the Archean Beardmore–Geraldton Greenstone Belt, Eastern Wabigoon Subprovince

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INTRODUCTION

The Phoenix Bedrock Mapping Project is an economic development initiative financially supported by an Industry Canada (through FedNor) allocation to the Lake Nipigon Heritage Authority; and conducted by the Precambrian Geoscience Section of the Ontario Geological Survey. The objective of the project is to conduct bedrock mapping at 1:20 000 and 1:50 000 scale in a large area, east of Lake Nipigon and west of Beardmore that was burnt during a major forest fire in 1999 (*see also* Hart et al., this volume, Figure 20.1). The fire has enhanced outcrop exposure in most of Kitto, Eva and Dorothea townships and parts of Summers and Sandra townships providing an opportunity to collect new geoscience information. The Beardmore area has mineral resource potential for gold, volcanogenic massive sulphide (VMS) mineralization and magmatic platinum group element (PGE) mineralization. The objective of this project is that this new information will generate interest in prospecting, mineral exploration and investment and create and/or maintain community-based jobs and opportunities for the Municipality of Greenstone and the surrounding area.

This portion of the Phoenix project evaluated 1) the economic potential of the Archean supracrustal rocks; and 2) the position of the metasedimentary and metavolcanic rocks of the Beardmore–Geraldton Belt (BGB) within the tectonostratigraphic framework of the eastern Wabigoon Subprovince.

Beardmore is located approximately 190 km northeast of Thunder Bay and east of Lake Nipigon. Access is provided by the Canadian National Railway (CNR), Highway 11, logging roads extending north and south from Highway 580, and the shore of Lake Nipigon. Previous geological work on the Archean supracrustal rocks was conducted by Mackasey (1975) and Shanks (1993) as part of the 1:20 000 scale mapping of Dorothea and Sandra, and Eva and Summers townships, respectively. However, Kitto Township has never been mapped at 1:20 000 scale. Mapping on a 1:50 000 scale was completed in Kitto and southern Eva townships by Sutcliffe and Greenwood (1985). Detailed lithogeochemical sampling of the metavolcanic rocks was conducted by Tomlinson et al. (1996). A preliminary investigation of the potential for structurally controlled mesothermal gold mineralization was completed by DeWolfe (2001). Exploration and prospecting in the surrounding area was initially conducted mainly for iron ore in the early 1900s, but expanded to gold in 1925 (Mason and White 1986). The area has been extensively explored for gold and, to a lesser extent, for base metals, and hosts a number of showings as well as the past-producing Leitch and Sand River mines. A systematic comparison of the rocks within the different sub-belts of the BGB and an evaluation of their mineral potential has not previously been completed.

GENERAL GEOLOGY

The Phoenix project area is underlain by Archean metasedimentary and metavolcanic rocks of the Beardmore–Geraldton Belt (BGB), which forms the southern margin of the eastern Wabigoon Subprovince. The BGB is bounded to the south by metasedimentary rocks of the Quetico Subprovince and to the north by metavolcanic rocks of the Onaman–Tashota greenstone belt (*see also* Hart et al., this volume, Figure 20.2). The belt is interpreted to represent the collisional zone formed between the Wabigoon and Wawa subprovinces (Devaney and Williams 1989; Shanks 1993; Tomlinson et al. 1996).

The BGB has been subdivided into a series of 3 northeast-striking metasedimentary–metavolcanic sub-belts by Devaney and Williams (1989). Mafic metavolcanic rocks of the Southern Volcanic sub-belt (SVB) consist of massive flows, pillowed flows, minor tuffs and interflow chert-magnetite iron formations. The Southern Sedimentary sub-belt (SSB) is composed of finely to thickly bedded feldspathic wacke, lithic wacke, siltstone, polymictic conglomerate, and mudstone and/or argillite with an argillite-magnetite iron formation and jasper-hematite iron formation providing stratigraphic markers within the SSB. The Central Volcanic sub-belt (CVB) consists of massive mafic flows, pillowed flows, minor tuffs, lapilli tuffs and tuff breccias, minor intermediate flows, tuffs and tuff breccias, and interflow chert-magnetite iron formations. Exposures of the Central Sedimentary sub-belt (CSB) consist of polymicitic conglomerate, lithic arenite, and an argillite-magnetite iron formation. The Northern Volcanic sub-belt (NVB) is subdivided, in this article, into a north mafic Bish Bay assemblage and a southern intermediate Poplar Point assemblage. The Bish Bay assemblage is composed of pillowed to massive flows and rare tuffs. The Poplar Point assemblage consists of intermediate flows, tuff breccias and tuffs interbedded with mafic massive and pillowed flows and tuff breccias. Supracrustal rocks of the Poplar Point assemblage are intruded by a series of granodiorite bodies with massive, quartz porphyritic, feldspar porphyritic, and feldspar–quartz porphyritic phases emplaced along the regional foliation. Thin gabbro sills intrude the supracrustal rocks of all three metasedimentary and metavolcanic sub-belts.

A swarm of narrow, north-trending diabase dikes cut the metasedimentary and metavolcanic rocks of the BGB. Limestone and arenite units of the Proterozoic Sibley Group are exposed at an unconformity with underlying Quetico Subprovince metasedimentary rocks along Highway 11 in southeast Kitto Township. A Proterozoic intrusion consisting of olivine pyroxenite and pyroxene peridotite forms a ring-shaped intrusive feature in western Kitto Township (*see also* Hart et al., this volume, Figure 20.2). Proterozoic diabase sills intrude and overlie all other units. Quaternary raised beach sand deposits form an extensive cover along Lake Nipigon, south of Poplar Lodge and along the Devil's Walk. Extensive glaciofluvial deposits occur in south-central Kitto Township. Deformation increases toward the southeast and metamorphic grade varies from middle to upper greenschist facies in the north, to amphibolite facies toward the southeast along the contact with the Quetico Subprovince.

Metavolcanic Rocks

The SVB is predominantly pillowed to massive basaltic flows and pillow fragment breccias interlayered with minor mafic tuff and lapilli tuff. The pillowed flows are amygdaloidal to vesicular with quartz and/or carbonate fillings, and are variably deformed with some pillows stretched to a 1:20 (height:length) aspect ratio. Deformation decreases toward the west and a number of reliable north-facing top determinations were made along the shore of Lake Nipigon. Variolitic pillowed and massive flows with irregular variolitic bands and patches occur at a number of different stratigraphic horizons in the SVB. A very coarse-grained plagioclase porphyritic flow was identified in two separate horizons with a sequence, up to 250 m thick, located along the southern edge of the SVB. These porphyritic flows resemble feeder flows present in the Whitton assemblage of the Heaven Lake greenstone belt (Hart and MacDonald 2000), but could also represent shallow-level gabbroic feeder sills for overlying flows.

Mafic metavolcanic rocks, consisting of massive to pillowed flows, pillow fragment breccias, with lesser tuffs and lapilli tuffs, predominate in the CVB. The pillowed flows are amygdaloidal to vesicular with quartz and/or carbonate fillings, but variolitic textures are lacking. Well-preserved primary textures, such as concentric flow laminae in lava tubes and pillow breccia, are exposed along Lake Nipigon in Eva Township. Deformation increases to the east, especially within the folded contact of the SSB and CVB. Tuffs and lapilli tuffs are more abundant toward the east, with lapilli clasts commonly either more siliceous and vesicular or of a quartz porphyritic composition. Thin horizons of flows, pillowed flow, and tuff breccias, with limited strike extent, occur at a number of stratigraphic positions and are distinguished by a more siliceous and/or feldspar porphyritic nature. The tuff breccias have clasts and matrix with a similar feldspar porphyritic composition with minor quartz porphyritic clasts. These horizons may be andesitic rather than intermediate in composition.

The NVB is subdivided into a northern Bish Bay and southern Poplar Point assemblage. The Bish Bay mafic assemblage consists of massive to pillowed flows with minor tuffs and lacks significant interflow chemical metasediments. The southern Poplar Point assemblage contains a series of interbedded intermediate and mafic metavolcanic flows and tuff breccias with minor interflow intermediate tuffs and cherts. Intermediate flows are massive to pillowed with vesicular to quartz amygdaloidal or feldspar porphyritic textures interpreted to indicate an altered andesite composition. The tuff breccias were classified based on the predominant clast population, with mafic breccia containing less than 10% intermediate clasts and intermediate breccias containing less than 5% mafic clasts. Monolithic intermediate tuff breccias may be the result of autobrecciation of the underlying massive highly vesicular intermediate flows. The matrix is moderately to highly altered, but the clasts usually lack reaction rims and commonly have well-preserved primary textures (Photo 21.1). Tuffs are thinly bedded with minor amounts of chert forming horizons up to 20 m thick, and, in one example, draped over pillows. Mafic flows vary from massive, gabbroic textured with rare, fine-grained plagioclase; to pillows with varioles or thick brown selvages, drainage shelves as open cavities, and abundant well-preserved interpillow hyaloclastite (Photo 21.2).

Chemical Metasedimentary Rocks

The chemical metasedimentary rocks consist of oxide-facies iron formations within the metavolcanic rocks of the SVB and CVB, and a jasper-hematite iron formation in the SSB. The interflow iron formations are usually irregular 0.1 to 0.3 m (but possibly up to a metre) thick units composed of mainly chert with minor magnetite-rich beds. These iron formations are often highly disrupted and, in some locations in the CVB, form chert-magnetite breccias. This irregular nature may be due to either deposition on an irregular substrate, possibly pillowed flows, or the accommodation of a higher percentage of the regional strain. The iron formations within the SVB are laterally continuous and traceable using the regional airborne geophysical magnetic survey (OGS 1998), however, the units within the CVB appear to be discontinuous. Rare, grey, interflow cherty metasediments may be either deformed quartz veins or highly attenuated portions of lean oxide-facies iron formations. The jasper-hematite iron formation consists of thin beds of jasper, specular hematite, and mudstone with a very low magnetite content hosted by metasedimentary rocks of the northern part of the SSB. This unit is only observed in the area around the Leitch Mine, which is also the area of the regional fold in the SSB–CVB contact.

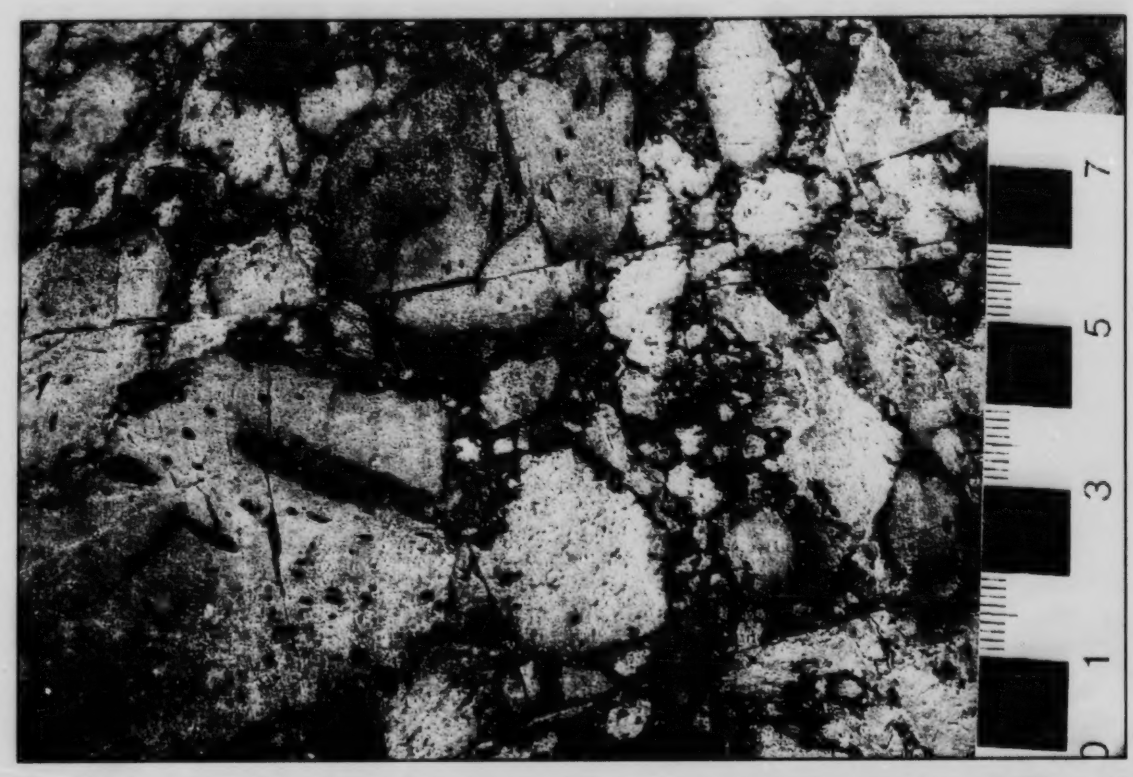

Photo 21.1. Clasts of vesicular intermediate flow; an example of the well-preserved primary textures of clasts in the tuff breccias of the Poplar Point assemblage.

Clastic Metasedimentary Rocks

Rocks of the SSB consist of feldspathic wacke, lithic wacke, siltstone, and mudstone and/or argillite, rare arenite beds and an argillite-magnetite iron formation. The feldspathic wackes are poorly sorted to graded, with 3 to 30 cm thick beds and occasional beds greater than 1.0 m. Load casts and flame structures may be present along contacts with argillite beds, and occasional channel scours are observed. The argillites have less than 0.3 to 3 cm beds forming 0.1 to 1.0 m thick bed sets within predominantly wacke and siltstone horizons. Finely laminated argillite-magnetite iron formation consists of mudstone with variable amounts of magnetite, occasional interbedded siltstone and rare jasper beds. Four separate iron formation horizons are present in one location, but generally only one horizon is observed. This suggests that the multiple horizons and unit thickness is, in part, the result of a structural repetition associated with regional deformation and/or soft sediment deformation. A polymictic, clast-supported conglomerate contains granitic clasts, a variety of volcanic clasts, and rare quartz and jasper clasts in a chloritic wacke matrix. This conglomerate forms channel deposits along the south side of the argillite-magnetite iron formation and along the north boundary of the SSB. The metasedimentary rocks of the SSB have been interpreted to represent deep-water turbidites (Bouma A + E) by Shanks (1993).

The exposures of CSB in southern Dorothea and northern Summers townships consist of polymictic conglomerate, lithic arenite, and an argillite-magnetite iron formation. The conglomerate is thickly bedded and clast supported containing well-rounded granitic clasts, a variety of volcanic clasts and minor quartz in an arenite matrix. The conglomerate is interbedded with less than 0.5 m thick feldspathic

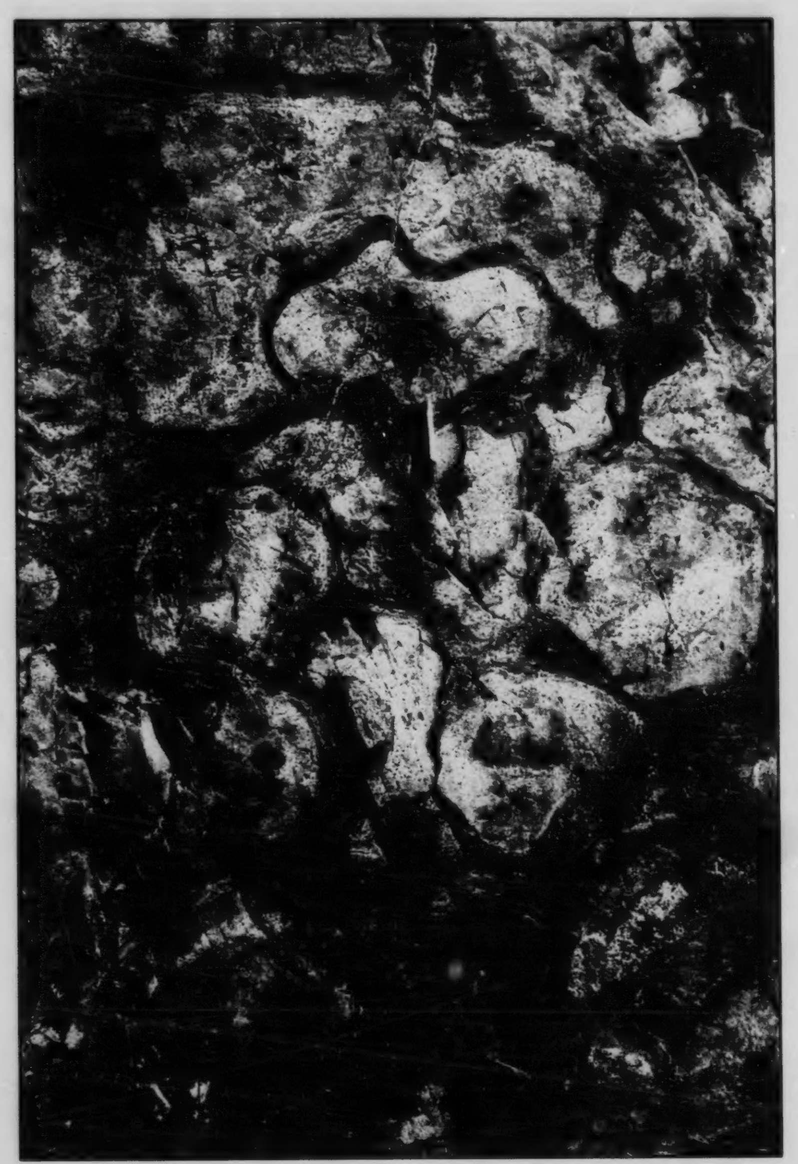

Photo 21.2. Pillowed flow with thick brown selvages, drainage shelf as an open cavity in lower right, and abundant well-preserved interpillow hyaloclastite; tops indicate beds dipping at less than 40° to the west.

arenite beds with occasional clasts of the same composition as the conglomerate. Individual beds of conglomerate and arenite are difficult to trace on an outcrop scale, which suggests that they were formed as channel deposits. A conglomerate unit with 1% jasper and iron formation clasts forms a distinctive horizon along the southern contact with the lithic arenite. The lithic arenite contains 5 to 10% sand-size fragments of jasper and occasional well-rounded pebble-size clasts, but no bedding is evident. A finely laminated to thinly bedded argillite-magnetite iron formation, consisting of mudstone with variable amounts of magnetite interbedded with thinly bedded siltstone and minor amounts of chert, is located along the northern side of the CSB.

Metasedimentary rocks of the Quetico Subprovince are exposed along the southeast and east side of Kitto Township. The rocks consist of feldspathic wackes, siltstones, and conglomerate resembling units of the SSB, but are distinguished by the presence of biotite. The conglomerate is matrix supported and dominated by highly flattened mafic and intermediate volcanic clasts in a matrix of feldspathic wacke.

Mafic and Ultramafic Intrusions

A number of 25 to 50 m thick, medium-grained, massive, gabbro sills intrude the metavolcanic and metasedimentary units of the BGB. These sills are generally more leucocratic and coarser grained than the massive flows. A sill located to the west of the Sand River Mine has chill contacts with the metasedimentary rocks, which is interpreted to indicate that the sills are younger than the supracrustal units of the BGB. However, the lack of contacts in all cases means that some of the sills may represent subvolcanic feeder sills for the metavolcanic sequences that they intrude.

A series of diorite to gabbro sills occur near the contacts of the Poplar Point assemblage. A diorite sill intrudes into the mafic metavolcanic rocks near the contact between the Bish Bay and Poplar Point assemblages. The diorite is massive, fine to medium grained, greenish grey, and is bounded by sheared metavolcanic rocks. These sheared metavolcanic rocks host the northern gold-bearing and southern molybdenite-bearing quartz veins of the Tyson property. Similar dioritic rocks are present along the southern contact of the Poplar Point assemblage and in rocks of the CSB.

A 20 m wide peridotite sill intrudes the mafic metavolcanics of the Bish Bay assemblage in the area north of Bish Bay. The peridotite weathers a distinctive reddish brown colour, with a very dark green fresh surface. This sill has been traced for more than a kilometre along strike to the east.

Intermediate to Felsic Intrusions

A series of massive, medium-grained granodiorite dikes, ranging from about 0.5 to 5 m in width, intrude the metavolcanic rocks of the Poplar Point assemblage in the NVB, usually perpendicular to bedding. The dikes range from massive granodiorite to feldspar, quartz, and feldspar-quartz porphyritic rocks. These units are not observed in contact with each other, but are spatially associated, which is interpreted to indicate a genetic relationship between the different dikes. The timing of the intrusive event is not known, but one exposure of feldspar-quartz porphyritic dike appears to brecciate into a tuff breccia with the number of porphyritic clasts decreasing away from the dike margins and disaggregation of the clasts into simple or individual mineral grains. These textures are interpreted to be peperites, and indicative of synvolcanic origin as either a cryptodome or subvolcanic dikes intruding into a wet, unconsolidated volcanic pile.

Structural Geology

The BGB is a structurally complex belt that has been interpreted to be the result of isoclinal folding (e.g., Mackasey 1975; Shanks 1993) or dextral strike–shear imposed on an imbricated thrust stack (Devaney and Williams 1989), with the difference in interpretations being a result of limited reliable top indicators and the unknown significance of the cleavage. Generally, deformation within the BGB decreases to the west resulting in an increase in preserved primary structures. Bedding in the BGB generally strikes northeast with dips varying from steeply north to steeply south. Pillow tops indicate at least two folds along a northeast-trending axis in the SVB, but are consistently north-trending throughout the CVB and Bish Bay assemblage. Graded bedding in the SSB is overturned with at least two top reversals about a northeast-trending, southwest plunging fold axis. Load structures and soft sediment deformation are apparent in some beds, however, there is a weakly to moderately well-developed bedding-parallel foliation in some locations, termed "layer-parallel shear" by Shanks (1993). False cross-bedding structures are present, due to a 10 to 20° counterclockwise difference between the strike of bedding and a second foliation, termed "tectonic foliation" by Shanks (1993) and "S_2 schistosity" by DeWolfe et al. (2000). This foliation is often well developed in the argillites and the coarser clastic beds next to the argillites. The Poplar Point assemblage, in Dorothea Township, has bedding and tops indicating north strikes with shallow dips and tops to the west, and a very weak cleavage. One interpretation of the weak development of a foliation in this assemblage is that the Poplar Point assemblage behaved as an isolated rigid block during most of the regional deformation.

Contacts between sub-belts are marked by angular conformity (e.g., SSB–CVB contact) with subparallel to coincident zones of heterogeneous ductile shear (e.g., Empire fault; Shanks 1993). The SSB–SVB contact in the Beardmore area is defined by the southwest-striking, south-dipping, graphitic, Empire fault (Shanks 1993), however, the contact in western Kitto Township appears to be folded on a 100 m scale. A separate graphitic shear, possibly related to an iron formation, is located near the centre of the SVB in western Kitto Township. The contact between the SSB and the CVB is a regional scale Z-fold defined by the reversal in top indicators in both the metasedimentary and metavolcanic rocks. Abundant northeast-trending shear zones, subparallel to the fold axis, are present in the rocks along the fold and the Sandy Creek–Sandra Lake fault (Shanks 1993; Mackasey 1975) and may be one of these faults. However, the argillite-magnetite iron formation in the SSB is regionally continuous with little evidence of folding on airborne geophysical maps (OGS 1998). Therefore, the dextral Standingstone Lake–Watson Lake fault, which is subparallel to the south limb of the regional Z-fold, may subdivide the SSB into a northern and southern assemblage. The CVB–CSB and CSB–NVB contacts are not exposed and there are few indicators of faulting or folding in the surrounding rocks. A fault is interpreted to pass through Bish Bay close to the boundary between the Bish Bay and Poplar Point assemblages. The Paint Lake fault is well exposed along the shore of Lake Nipigon, north of Devil's Walk, in northwest Dorothea Township. Metavolcanic rocks within the fault zone are intensely deformed with a dextral sense of shear, that Mackasey (1975) estimated to have an 800 m horizontal displacement.

The Wabigoon–Quetico subprovinces boundary is marked by an increase in deformation and is interpreted to be coincident with the northeast-trending Blackwater fault (Shanks 1993). A low angle bedding–cleavage relationship, comparable to the bedding–tectonic foliation relationship observed in the SSB, is also present in the Quetico Subprovince metasedimentary rocks.

Alteration and Mineralization

Alteration in the metavolcanic and metasedimentary rocks is generally weak to moderate with intense alteration limited to zones tens of metres thick. Alteration is best developed in the mafic metavolcanic rocks and often associated with shearing along the sub-belt contacts. Carbonatization is commonly a result of a combination of calcite and ankerite and ranges from disseminated grains in the metasedimentary rocks to weak to intense pervasive alteration of the mafic metavolcanic rocks. Examples of intense carbonatization within the mafic metavolcanic rocks are exposed in sheared rocks along the logging road northwest of Eva Lake, and in the CVB rocks along the limbs of the Z-fold north and south of the 72 Road. Chlorite alteration is commonly weak to moderately pervasive in most mafic metavolcanic rocks of the BGB, with the exception of a number of argillite beds and mafic metavolcanic rocks associated with granodiorite dikes. The chloritic argillites are generally less than 0.25 m thick and not traceable between outcrops, and contain up to 10% euhedral, medium-grained pyrite. The chlorite associated with dikes is present in both the matrix of a tuff breccia and as total replacement of interpillow hyaloclastite in the Poplar Point assemblage and, in both cases, is interpreted to be a result of hydrothermal activity during intrusion of the dikes. Epidote alteration is highly variable, and appears to be related to diabase dikes (Hart et al., this volume) and hydrothermal and/or intrusive activity in the Poplar Point assemblage. In the Poplar Point assemblage, epidote alteration occurs along fractures in flows and tuff breccia and in interpillow spaces and may also be associated with the intrusion of the granodiorite dikes. A series of late extensional veins composed of quartz, calcite, and/or epidote and axinite occur in intensely iron carbonatized mafic metavolcanic flows in the immediate area of the Z-fold in the SSB–CVB contact and in weakly altered rocks of the NVB north of the Bish Bay fault. Axinite $[(Ca,Mn)_3Al_2BO_3(Si_4O_{12})OH]$ is a light purple mineral, identified along with riebeckite by X-ray diffraction analyses (Geoscience Laboratories, Ontario Geoservices Centre, Sudbury) commonly associated with contact metamorphic zones associated with granites and diabase intrusions.

Gold production in the Beardmore area totalled over one million ounces, with the Leitch gold mine producing 847 690 ounces Au at a grade of 0.92 ounces of gold per ton, the Sand River gold mine producing 50 065 ounces Au at a grade of 0.32 ounces of gold per ton, and the Northern Empire Mine producing 149 493 ounces Au at a grade of 0.35 ounces of gold per ton (Mason and White 1986). Gold mineralization in these mines, and the showings in the map area, is generally associated with foliation-parallel crackseal or shear–fault quartz veining. The Leitch and Sand River gold mines are crackseal-textured quartz veins with variable amounts of pyrite, arsenopyrite, chalcopyrite and tetrahedrite, and septa of sericitic and carbonatized wall rocks. The veins are hosted by dilatant zones in a foliation-parallel orientation within the metasedimentary rocks of the SSB, and these structures have been interpreted by Shanks (1993) to be related to shearing either along the limbs of the regional Z-fold or later shear in a transpression zone. The Northern Empire Mine is hosted by a series of *en échelon* quartz veins containing variable amounts of pyrite, arsenopyrite, pyrrhotite and chalcopyrite hosted by carbonatized, sheared metavolcanic rocks near a regional fault. Quartz veining within brittle features of deformed iron formations were considered by Shanks (1993) to be part of the shear–fault style of mineralization. Gold mineralization in these brittle features is hosted by early quartz stringers following the shear zones, which contain arsenopyrite, pyrite, pyrrhotite and chalcopyrite. Veins sampled during this project include both extensional and foliation-parallel veins commonly consisting of white quartz with variable amounts of carbonate (ankerite and calcite), chlorite, and/or black tourmaline. Sulphide mineral content varies from trace to 1% fine-grained disseminated pyrite in the veins; and 5 to 10%, fine- to medium-grained, disseminated cubic pyrite in 0.5 to 3 cm wide chloritic shears bounding some veins. Veins within the metasedimentary rocks of the SSB are mainly foliation parallel with generally weak to very weak carbonate and chlorite wall rock alteration. The SSB also hosts a few examples of late extensional veins. The metavolcanic rocks host late extensional veins associated with weak alteration in all 3 sub-belts. However, wall rocks that host foliation-parallel and shear-hosted veins are moderately to intensely carbonatized. Few of the veins that were sampled during this project contained sulphide minerals, such as arsenopyrite, with the most noticeable exceptions being at the A. Lafontaine – Buffalo–Beardmore prospect and the R. Cote–Archie Lake gold prospect, both of which are in Summers Township (*see also* Hart et al., this volume, Figure 20.1). The Buffalo–Beardmore mineralization is associated with quartz veining, and pyrite, arsenopyrite and pyrrhotite mineralization, in a deformed iron formation. The Archie Lake gold mineralization is a recent discovery consisting of quartz veining, with arsenopyrite, pyrite and chalcopyrite mineralization, in a sheared and variably carbonatized mafic metavolcanic rock. Veining is hosted by a shear subparallel to the Sandy Creek fault and the north limb of the regional Z-fold. Assays for all samples are pending. A molybdenite occurrence (*see also* Hart et al., this volume, Figure 20.1), the Tyson No. 3 vein, is hosted by a white, foliation-parallel quartz vein within sheared mafic metavolcanic rocks along the south boundary of the Bish Bay assemblage. The vein has 2 to 5 % coarse-grained molybdenite with 3 to 5% iron carbonate.

The best examples of base metal mineralization are located along the SSB–CVB contact and the Poplar Point assemblage of the NVB, and include vein-hosted and disseminated sulphide minerals. A white quartz vein, in rocks of the SSB south of Eva Lake and the contact, contains malachite, 1% disseminated chalcopyrite and 2 to 3% pyrite and was sampled for base metals. East along the contact, trace to 1% very fine-grained pyrite and pyrrhotite in fractures and vesicles within mafic metavolcanic rocks were sampled along the 72 Road. These same mafic metavolcanic flows also host bands, up to 2 cm wide, of semi-massive pyrite and pyrrhotite. Sulphide mineralization in the Poplar Point assemblage consists of pyrite and pyrrhotite with minor chalcopyrite as interpillow pods and vesicle fillings in mafic metavolcanic flows; as patches in the matrix of tuff breccias; in quartz veins in the intermediate metavolcanic flows; and along fractures in the granodiorite dikes. This sulphide mineralization is present in the area identified as the Montmorr or Hopkins occurrence (*see* Photo 21.1) (Mason and White 1986; Mackasey 1975). The occurrence of sulphide minerals in the tuff breccias correlates with the amount of chlorite in the matrix and the percent of porphyritic felsic intrusive clasts. Quartz veins with 3 to 5% coarse-grained, subhedral pyrite and 1% malachite and/or chalcopyrite, hosted by massive intermediate flows, were sampled in the area stratigraphically below the mineralized tuff breccias. The porphyritic phases of the granodiorite contained 1% disseminated coarse-grained euhedral pyrite along fractures. The occurrence of sulphide mineralization with quartz veins in the Eva Lake area and Poplar Point assemblage is interpreted to indicate a similar mode of formation. The close association between sulphide mineralization and felsic intrusive rocks in the Poplar Point assemblage suggests a genetic connection between the mineralization and intrusive rocks related to the intrusion of S-type granites. However, sulphide mineralization occurring as vesicle fillings and in interpillow spaces has been observed in the footwall zones of some VMS deposits (e.g., Ansil Mine; H.L. Gibson, Laurentian University, personal communication, 2000). The base metal sulphide mineralization may be two separate events with an overprint of an earlier VMS hydrothermal system by a later intrusive-related hydrothermal system. All assays from these areas are pending.

TECTONOSTRATIGRAPHIC DISCUSSION

The current interpretation of the position of the Quetico–Wabigoon subprovinces boundary does not appear to correlate well from the east to the west sides of Lake Nipigon. On the east side of the lake, the north to south stratigraphic sequence is the Onaman–Tashota greenstone belt; the BGB metasedimentary–metavolcanic sub-belts; with the Wabigoon–Quetico subprovinces boundary interpreted to occur along the south side of the SVB of the BGB (Williams 1991). On the west side of the lake, the Heaven Lake – Lac des Iles greenstone-granite terrane is bounded to the south by the Max Creek conglomerate, interpreted to be the most northern unit of the Quetico Subprovince (Percival and Sullivan 1989). There are regionally continuous iron formations in the BGB that are traceable by airborne magnetic geophysical surveys under Lake Nipigon and the diabase sills and appear to correlate with the iron formations within the metavolcanic and metasedimentary rocks of the Quetico Subprovince (Gupta 1991). A radiometric age determination is required in the BGB to aid in clarifying this correlation of the subprovince boundary.

The current interpretation of the subprovince boundary has a number of implications. Comparisons have been made between the Quetico Subprovince-type mafic to ultramafic intrusions (e.g., Samuels Lake) and the intrusions along the south side of the Wabigoon Subprovince (e.g., Lac des Iles, Legris; Pettigrew, Hattori and Percival 2000). Middleton (2000) has suggested that the Wabigoon–Quetico subprovinces boundary fault and the Paint Lake fault were active in the Mesoproterozoic and exerted a control on the emplacement of the ultramafic intrusions and diabase sills and dikes of the Lake Nipigon area. The position of the subprovince boundary becomes important in guiding whether exploration for platinum group element mineralization could be extended to include both Proterozoic-type and Quetico Subprovince-type ultramafic intrusions along the BGB and south into the Quetico Subprovince, or possibly extended north into the southern portions of the Onaman–Tashota greenstone belt.

RECOMMENDATIONS

The metavolcanic rocks and iron formation in west Kitto Township are the strike extension of the stratigraphy that hosts gold mineralization in the Beardmore area. Shear zones similar to those observed at known gold properties to the east also extend into Kitto Township, however, iron carbonate alteration is not as intense. The rocks in Kitto Township have been explored for gold in the past, as is evident from a number of overgrown test pits in iron formations, but have not been prospected recently or during this project. A re-examination of these rocks for gold mineralization is warranted.

The Poplar Point assemblage is a complex, but well–preserved, volcanic assemblage that requires detailed mapping on a 1:10 000 or 1:5000 scale to properly develop a complete understanding of the metavolcanic stratigraphy. This assemblage would provide an excellent area for a graduate level mapping thesis in volcanology due to the excellent preservation of the supracrustal rocks. Detailed mapping would provide the basis for understanding the base metal sulphide occurrences that are present in the assemblage.

Investigation of the sulphide mineralization associated with the SSB–CVB contact and the Poplar Point assemblage will be conducted as part of this project, but additional prospecting in these areas is required. Along the SSB–CVB contact, particular attention should be given to sulphide mineralization associated with northeast-trending shears, intense carbonate mineralization and/or quartz-calcite-axinite veining both in the SSB and the CVB. The area of interest should also include the CVB along strike, to the east of the 72 Road. The Poplar Point assemblage should be prospected with special attention given to the northerly strike of the metavolcanic rocks, as past work has assumed a northeast strike as is present in the rest of the NVB.

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22. Project Unit 01-008. Potential for Broken Hill-Type Mineralization in the Ontario Grenville Province

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INTRODUCTION

This paper presents a re-examination of previous suggestions that parts of the Central Gneiss Belt of the Grenville Province (Figure 22.1) may host Broken Hill-type zinc-lead mineralization (e.g., Easton and Fyon 1992; C. Marmont, personal communications, 1997 to 1999). This re-examination is the result of information shared between the Geological Survey of New South Wales in Australia and the Ontario Geological Survey, which was made possible by a twinning arrangement between the 2 organizations.

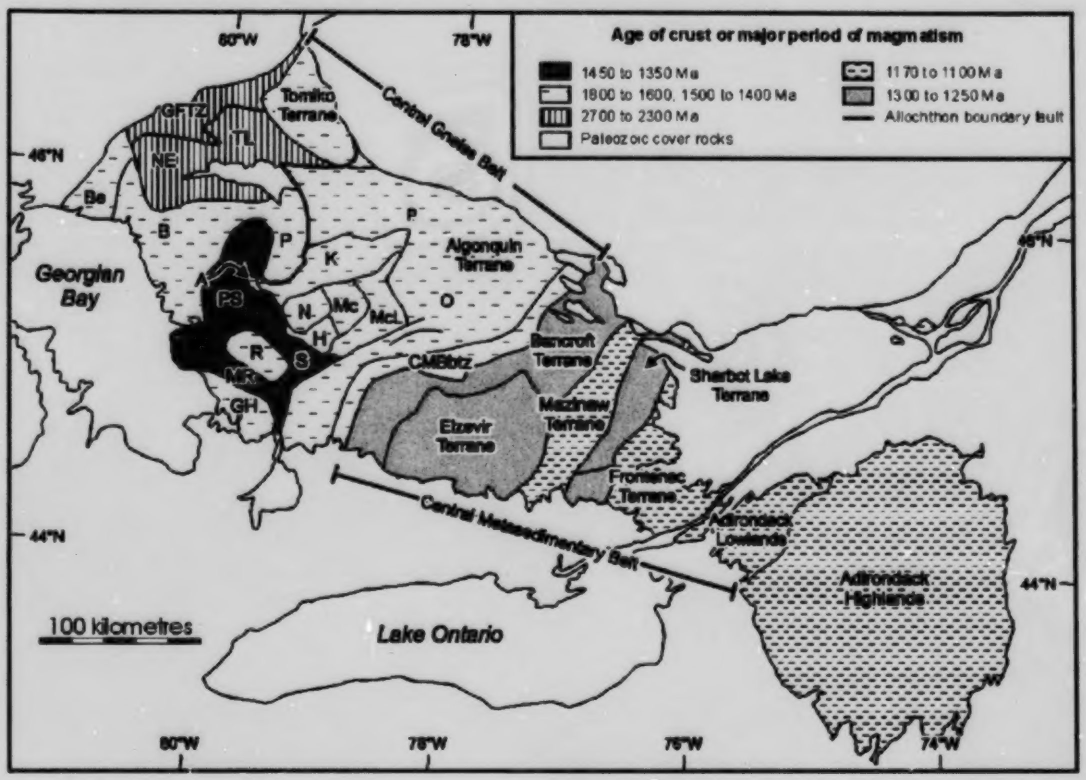
The previous suggestions were based largely on 3 points of comparison, namely: 1) the Paleoproterozoic (~1800 Ma) age of the rocks; 2) the high-metamorphic grade of the Broken Hill deposit (granulite facies); and 3) the occurrence of mineralization in a metasedimentary (paragneiss)-dominated sequence. Determination of more precise target areas for exploration in Ontario has been hampered, however, by the following: 1) lack of consensus in the literature on the key geological elements present in Broken Hill itself (e.g., the presence or absence of volcanic rocks and the importance of stratigraphy *versus* structure with respect to the regional map pattern, *etc.*); and 2) the lack of detailed (less than 1:250 000 scale) mapping within the Central Gneiss Belt.

KEY ELEMENTS OF BROKEN HILL GEOLOGY

The Broken Hill lead-zinc-silver orebody is hosted by the Paleoproterozoic Willyama Supergroup and is located near the boundary between the states of New South Wales and Southern Australia (Figure 22.2). The Paleoproterozoic rocks are unconformably overlain by Neoproterozoic (Adelaidean) sedimentary and minor volcanic rocks. The Willyama Supergroup comprises lower amphibolite to hornblende granulite facies metamorphic rocks with minor post-metamorphic intrusions, and was deformed at least 3 times during the Olarian orogeny (circa 1600 Ma) and again during the Delamerian Orogeny (circa 500 Ma) (Stevens, Gibson and Page 2000).

Siliciclastic metasedimentary and migmatitic rocks form the majority of the rocks in the Willyama Supergroup (Figure 22.3). Also present are substantial bodies of quartzofeldspathic gneiss, large and small pegmatite bodies, mafic gneisses (amphibolite and mafic granulite) and minor calc-silicate rocks, banded iron formations and quartz-gahnite, garnet-quartzite and garnetite "lode" rocks.

The Broken Hill lead-zinc-silver orebody, which has produced over 180 million tonnes of ore from 3 main mines since 1883, occurs near the top of the Broken Hill Group (*see* Figure 22.3). Many smaller orebodies of similar composition occur throughout the Broken Hill district, and all but a few are hosted in the Broken Hill Group (*see* Figure 22.3). In addition to the lead-zinc-silver Broken Hill-type deposits, several other deposit types are present, including copper and cobalt associated with iron formations, stratabound tungsten-base metal deposits, and various vein-type deposits (e.g., Stevens, Barnes and Forbes 1990).


Age of crust or major period of magmatism
1450 to 1350 Ma
1800 to 1600, 1500 to 1400 Ma
2700 to 2300 Ma
Paleozoic cover rocks
1170 to 1100 Ma
1300 to 1250 Ma
Allochthon boundary fault
80°W
78°W
76°W
74°W
46°N
44°N
Tomiko Terrane
Central Gneiss Belt
GFTZ
TL
NE
Be
B
P
K
Algonquin Terrane
O
Georgian Bay
A
PS
N
Mc
McL
H
R
S
MR
GH
CMBbtz
Bancroft Terrane
Sharbot Lake Terrane
Mazinaw Terrane
Elzevir Terrane
Frontenac Terrane
Adirondack Lowlands
Adirondack Highlands
Central Metasedimentary Belt
100 kilometres
Lake Ontario

Abbreviations	
A	Ahmic Domain
B	Britt Domain
Be	Beaverstone Domain (part of Killarney magmatic belt)
CMBbtz	Central Metasedimentary Belt boundary thrust zone
GFTZ	Grenville Front Tectonic Zone
GH	Go Home Domain
H	Huntsville Domain
K	Kiosk Domain
M	Muskoka
Mc	McCraney Domain
McL	McClintock Domain
MR	Moon River Domain
N	Novar Domain
NE	Nepewassi Domain
O	Opeongo Domain
P	Powassan Domain
PS	Parry Sound Domain
R	Rosseau Domain
S	Seguin Domain
SD	Shawanaga Domain
TL	Tilden Lake Domain

Figure 22.1. Tectonic subdivisions of the Grenville Province (*modified from* Easton 1992). The French River area is located at the southwestern boundary of Nepewassai domain.

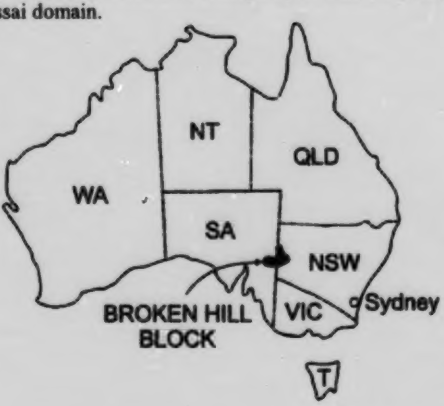

NT
QLD
WA
SA
NSW
Sydney
VIC
BROKEN HILL BLOCK
T

Figure 22.2. Sketch map of Australia showing the location of the Broken Hill deposit. Abbreviations: NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, Southern Australia; T, Tasmania; VIC, Victoria; WA, Western Australia.

Figure 22.3 outlines the main stratigraphic units of the Willyama Supergroup, along with the present age constraints on the succession (most are SHRIMP U/Pb ages on zircon). Mineralization is restricted to the Broken Hill Group, particularly rocks of the Freyers metasediments proximal to the Hores gneiss. Basement to the Willyama Supergroup has yet to be recognized. The age range of the Willyama Supergroup is 1700 to 1680 Ma; this is younger than the previously suggested age of approximately 1800 Ma. The key elements of Broken Hill geology, summarized from Stevens, Burton and Leyh (1998) and Stevens, Gibson and Page (2000) are outlined below in point form.

Depositional Environment

- extensional, likely at a continent margin
- volcanic starved, with some bimodal, tholeiitic volcanic rocks
- distal (no conglomerates); thin "volcanic units" (some of which may be sills)
- general fining upward of the sedimentary sequence
- rapid deposition (maximum 30 to 40 million years)
- variety of chemical sediments in the Broken Hill Group (various iron formation facies, tourmalinites (boron-rich rocks), manganese-rich rocks, calc-silicate rocks, evaporitic rocks). Some of the compositionally unusual rocks are probably the result of primary deposition or diagenetic processes (e.g., evaporitic, sabkha or playa lake environments?), whereas others may be the result of alteration and mineralization related processes

Mineralization

- associated with early pegmatite development in Broken Hill Group
- some control by Hores gneiss (felsic metavolcanic), possibly as a cap rock (in conjunction with overlying graphitic pelites of the Sundown Group)
- general association with part of succession containing amphibolites, felsic metavolcanics, aluminous and psammitic metasediments and chemical sediments
- pre-metamorphic
- one major orebody, many minor deposits
- ore mineralogy within the uppermost oxide zone of the deposit is complex, containing a variety of minerals such as coronadite, chlorargyrite, cerussite, malachite, azurite, anglesite, native copper, marmatite and rhodonite (e.g., van der Heyden and Edgecombe 1990). In contrast, the unweathered ore mineralogy consists of galena, sphalerite, chalcopyrite, arsenopyrite and loellingite, generally hosted in a quartz-garnet-gahnite rock (e.g., van der Heyden and Edgecombe 1990). Zinc-rich and lead-rich zones are present within the main deposit.
- the main and minor orebodies in the Broken Hill block do not have strong or distinctive aeromagnetic signatures, possibly reflecting the fact that sphalerite is not a good conductor, interference from iron formation horizons throughout sequence, and that even the high-resolution surveys are still coarser than the thickness of corresponding geological units

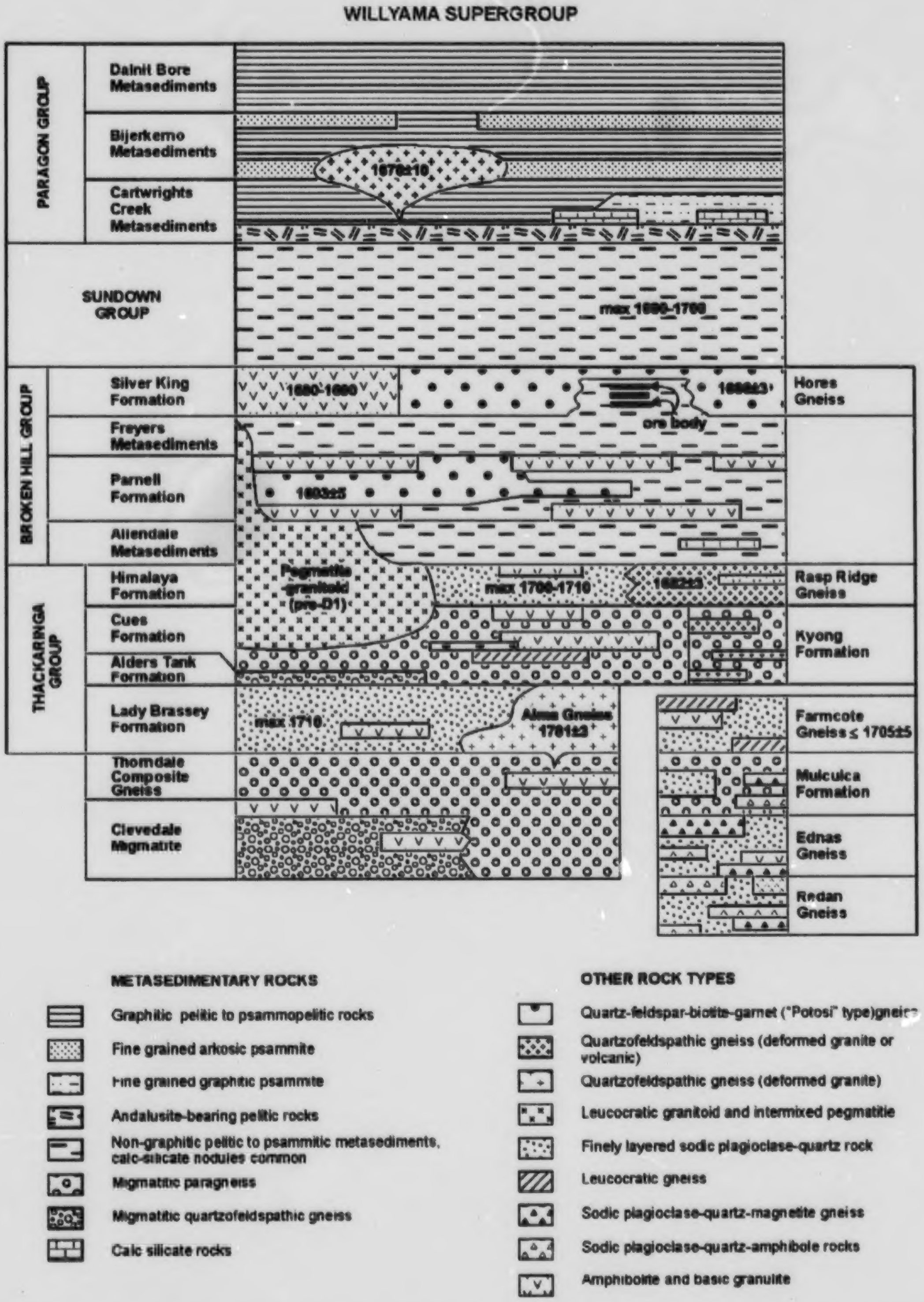

WILLYAMA SUPERGROUP
PARAGON GROUP
Dalnit Bore Metasediments
Bijerkemo Metasediments
1670±10
Cartwrights Creek Metasediments
SUNDOWN GROUP
max 1690-1700
BROKEN HILL GROUP
Silver King Formation
1680-1690
1686±3
Hores Gneiss
ore body
Freyers Metasediments
Parnell Formation
1693±5
Allendale Metasediments
THACKARINGA GROUP
Himalaya Formation
Pegmatite granitoid (pre-D1)
max 1700-1710
1682±3
Rasp Ridge Gneiss
Cues Formation
Kyong Formation
Alders Tank Formation
Lady Brassey Formation
max 1710
Alma Gneiss 1701±3
Farmcote Gneiss ≤ 1705±5
Thorndale Composite Gneiss
Mulculca Formation
Clevedale Migmatite
Ednas Gneiss
Redan Gneiss
METASEDIMENTARY ROCKS
Graphitic pelitic to psammopelitic rocks
Fine grained arkosic psammite
Fine grained graphitic psammite
Andalusite-bearing pelitic rocks
Non-graphitic pelitic to psammitic metasediments, calc-silicate nodules common
Migmatitic paragneiss
Migmatitic quartzofeldspathic gneiss
Calc silicate rocks
OTHER ROCK TYPES
Quartz-feldspar-biotite-garnet ("Potosi" type)gneiss
Quartzofeldspathic gneiss (deformed granite or volcanic)
Quartzofeldspathic gneiss (deformed granite)
Leucocratic granitoid and intermixed pegmatitie
Finely layered sodic plagioclase-quartz rock
Leucocratic gneiss
Sodic plagioclase-quartz-magnetite gneiss
Sodic plagioclase-quartz-amphibole rocks
Amphibolite and basic granulite

Figure 22.3. Stratigraphy, geochronology and simplified rock relatiosnhips within the Willyama Supergroup (*modified from* Stevens, Burton and Leyh 1998 and Stevens, Gibson and Page 2000).

Post-Ore History

- high-temperature, low- to moderate-pressure (~5 to 7 kb) metamorphism occurred less than 50 million years after deposition
- no recognized heat source (i.e., plutons) for metamorphism, low- to moderate-pressure and rapid onset of metamorphism constrains ability to invoke crustal thickening as a driving force for metamorphism
- higher grade rocks are generally those lowest in stratigraphy (achieved partial melting), this suggests heating from bottom up (a pattern not likely superimposed after younger orogenesis?)
- deformation (folding and thrusting) may have occurred prior to peak metamorphic conditions. One scenario is the development of a fold and thrust belt, which was then subjected to intense heating.

Other Points

- metasedimentary rocks in the Broken Hill Group are sillimanite-rich (does this indicate that the protolith was extremely rich in alumina or strongly altered?)
- geochemical data consists mostly of major element chemistry on possible mafic and felsic volcanic rocks, there is only, limited major element geochemistry on sedimentary rocks. Rare-earth element data on the volcanic and sedimentary rocks would assist in determining tectonic setting and provenance, respectively.
- the best available geochronology is single zircon grain work (non-abraded) on multiple zircon populations using the SHRIMP. This may not be the best approach for geochronology high-grade rocks of metasedimentary origin in order to determine depositional ages.
- stratigraphy appears to work in the belt

POTENTIAL OF THE CENTRAL GNEISS BELT, GRENVILLE PROVINCE

Difficulties in applying the Broken Hill model to the Grenville in Ontario include the following: 1) the lack of modern detailed mapping (<1:100 000 scale) over most of the region; 2) the presence of penetrative Grenvillian (1300 to 1000 Ma) deformation and metamorphism, which would have served to modify and obscure any earlier metamorphism that was close in age to sedimentation; 3) the lack of knowledge of the depositional setting of many candidate sedimentary sequences; and 4) the uncertainty as to whether or not the age (1700 to 1660 Ma) of the type area (Broken Hill) is of worldwide metallogenic significance.

After taking all of these factors into account, there are 3 areas within the Central Gneiss Belt that may have potential for hosting Broken Hill-type mineralization: the Tomiko terrane, the French River area, and metasediment-dominated domains within the Algonquin terrane. Each region will be discussed in turn. It should be noted that these target areas are speculative, and further mapping and geochronology is needed to fully evaluate the potential for Broken Hill-type mineralization in each area.

Tomiko Terrane

This terrane (*see* Figure 22.1) is located northeast of North Bay, and is bounded to the west by Highway 11, to the east by the Ottawa River, and to the south by Highway 17. Reconnaissance mapping by Lumbers (1971a, 1971b) and Moore (1976) exists for this terrane, with detailed mapping by Moore (1976) focussing on Butler, Antoine and Olrig townships. C. Marmont (personal communications, 1997 to 1999) has previously suggested that this terrane contains rocks with many similarities to those present in the Broken Hill region. Tomiko terrane is known to contain Archean rocks overlain by a Mesoproterozoic metasedimentary sequence that contains quartzite, calc-silicate rocks and, locally, magnetite-quartz iron formation (e.g., Easton 1992; Dickin and Guo 2001). Moore (1976) also describes pyrrhotite gneiss (sulphide-rich) horizons within part of the stratigraphy (Figure 22.4). Quartzite from the terrane has yielded a restricted zircon population of 1687 ± 20 Ma, interpreted as a depositional age, with metamorphism in the same quartzite occurring at 995 Ma (Krogh 1989). The restricted zircon population could be indicative of a volcaniclastic unit rather than an epiclastic unit. This single age falls in the same range as that of the Willyama Supergroup. Peak metamorphism conditions in Tomiko terrane may be in the 5 to 7 kb range for pressures, rather than the 10 kb range typical of most of the Central Gneiss Belt, and 650 to 725°C for temperatures. It should be noted that these pressures and temperatures reflect Grenville metamorphism, which would have overprinted any early metamorphic assemblage. Moore (1976) provides textural evidence of a two-stage metamorphic evolution in parts of this terrane.

In addition to the age of the rock, the stratigraphic sequence described by Moore (1976) (*see* Figure 22.4) has some similarities to the Willyama Supergroup, such as the presence of a psammitic sequence with amphibolite layers (Cahill Lake sequence = lower Freyers metasediments) overlain by a sequence of calc-silicate gneiss, pyrrhotite gneiss, pelitic gneiss and amphibolite (Crocan Lake sequence = upper Freyers metasediments or Sundown Group). Migmatitic rocks also occur within the region, although Moore (1976) was not able to determine their relationship to the other units. Magnetite-quartz oxide iron formation occurs in the terrane, and it is possible that silicate-facies iron formation may also be present. Notable differences are the apparent abundance of fairly mature quartzite within the succession (unlike the turbidite-dominated Willyama Supergroup), and the apparent absence of rocks with unusual mineralogy (e.g., boron rich, manganese rich, gahnite bearing). Kyanite-rich units in the terrane could be equivalent to the sillimanite-rich parts of the Broken Hill Group.

French River Area

The French River area hosts a sequence of paragneiss and quartzite, containing some amphibolite units, that have not been mapped in detail. Quartzite from the area yields an Archean zircon population (Krogh 1989) and amphibolites in the paragneiss sequence have zircon ages of 1744 ± 11 (Krogh 1989). The succession is not as compelling as that present in the Tomiko terrane, for example, it lacks iron formation and calc-silicate units, but, given the limited mapping coverage in the French River area, it remains a possible exploration target.

Algonquin Terrane

Three domains within Algonquin terrane have potential for hosting Broken Hill-type mineralization, if only because they contain paragneisses of roughly similar age. These are the northern Britt, Kiosk and Powassan domains (*see* Figure 22.1). The Kiosk and Powassan domains are known to contain large areas of graphitic rocks, and might be the best areas to examine first. The geology is complicated in this region by the abundance of plutons (~1450 Ma) and associated granulite-facies metamorphism, at approximately 1450 Ma, superimposed on the older rocks.

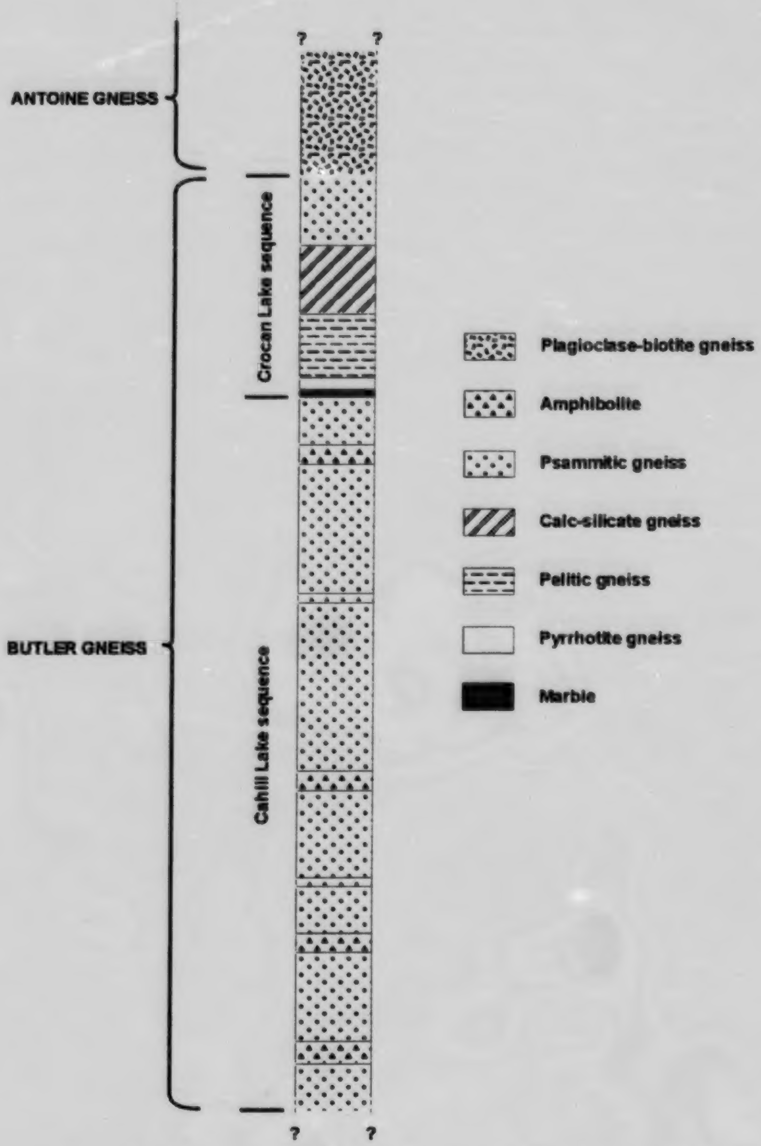

?
?
ANTOINE GNEISS
Crocan Lake sequence
BUTLER GNEISS
Cahill Lake sequence
?
?
Plagioclase-biotite gneiss
Amphibolite
Psammitic gneiss
Calc-silicate gneiss
Pelitic gneiss
Pyrrhotite gneiss
Marble

Figure 22.4. Stratigraphy of southern Tomiko terrane (*from* Moore 1976).

Exclusion of Other Areas

The majority of the domains lying south of the Allochthon Boundary Fault in the Central Gneiss Belt (*see* Figure 22.1), except for Parry Sound domain, are thought to have formed in an Andean-type continental-arc setting and are pluton dominated (e.g., Carr et al. 2000). Consequently, they are not considered to have potential for hosting Broken Hill-type mineralization because they do not seem to be in a favourable tectonic environment, nor do they contain volcanic-starved, metasedimentary successions. Nepewassi and Tilden Lake domains are not included because they consist predominantly of Archean rocks. Beaverstone domain (Killarney magmatic belt) is excluded because it represents a continental-arc setting. Most rocks within the Central Metasedimentary Belt formed in volcanic-arc or marginal-basin settings, and thus are excluded on the basis of tectonic environment.

The Frontenac Terrane–Adirondack Lowlands area (*see* Figure 22.1) is more problematic. High-temperature, low-pressure metamorphism followed deposition of a metasedimentary-dominated succession (no known volcanic rocks), deposited on unknown basement, possibly soon after deposition. Evaporitic and tourmaline (boron)-rich rocks are known to occur in the sequence in association with known zinc mineralization (e.g., Balmat–Edwards zinc mine and environs). Notable differences are 1) the heat source for metamorphism is provided by a suite of coeval plutons (~1170 to 1155 Ma); 2) the absence of any metavolcanic rocks or related sills; 3) the absence of iron formation; 4) the carbonate-dominated character of the metasedimentary sequence; and 5) the younger age of the rocks.

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23. Project Unit 01-008. Geology and Mineral Potential of Mafic Intrusions in Flett and Angus Townships, Grenville Province

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INTRODUCTION

Weakly to unmetamorphosed mafic intrusive rocks were first reported from Flett Township (Figures 23.1 and 23.2) by Barlow (1899), but little is known about the age or tectonic affinity of these mafic rocks. The latter questions are particularly important when it comes to evaluating the platinum group element (PGE) mineral potential of these mafic rocks; for example, are these rocks correlative with the East Bull Lake intrusive suite (2475 Ma), which has high PGE potential, or are they related to another, less prospective intrusive suite? Approximately 5 weeks of the 2001 field season were spent mapping and sampling these rocks in order to characterize their age, tectonic affinity and mineral potential.

GEOLOGICAL SETTING AND PREVIOUS WORK

Two mafic intrusions are located mainly in Flett Township, north of Fanny and Fall lakes, respectively (*see* Figures 23.1 and 23.2). The intrusions occur within the Grenville Front tectonic zone, roughly 32 km southeast of Temagami, and 10 to 12 km southeast of the Grenville Front (*see* Figures 23.1 and 23.2). Herein, the eastern body will be informally referred to as the Fall Lake intrusion, and the western body as the Fanny Lake intrusion (*see* Figure 23.2). Each will be described separately. Figures 23.3 and 23.4 are geological maps of the Fanny Lake and Fall Lake intrusions, respectively.

Subsequent to Barlow's (1899) initial description, Hurst (1932) described the O'Connor titaniferous magnetite occurrence and reported a single chemical analysis from the Fall Lake intrusion. Hurst's (1932) map shows the mafic intrusive rocks as a single body, however, Lumbers (1971a) showed them as 2 separate bodies of different relative age, an observation confirmed by this study. Lumbers (1971a, 1971b) mapped the intrusions as part of his regional mapping study of the Tomiko area, but did not describe them in detail. He assigned them a late-Grenvillian age and his maps suggested that the intrusions had relatively well-preserved cores with deformed and metamorphosed margins.

Exploration work, mainly for iron and titanium, was conducted on the intrusions in the 1930s, 1940s, 1950s and the early 1970s. From 1970 to 1972, W. Nicol explored for uranium in gneisses on the southwest shore of Fanny Lake. Between 1974 and 1996, the area was in the Temagami Land Caution and unavailable for staking. Exploration was renewed between 1996 and 1998 by Lake Superior Resources, who conducted geological mapping and aeromagnetic and radiometric geophysical surveys over the Fanny Lake intrusion in a search for nickel-copper-PGE mineralization (Racicot and Keevil 1998; Terraquest 1999). Lake Superior Resources also removed a test block from the Fanny Lake intrusion for evaluating building stone potential. In February 2001, Randsburg International Gold Corporation conducted induced-polarization and ground magnetometer geophysical surveys over the southern and the northeastern parts of the Fanny Lake intrusion. Temex Resources holds several claims immediately north of the intrusion, part of a larger claim block on which they are conducting a diamond exploration program.

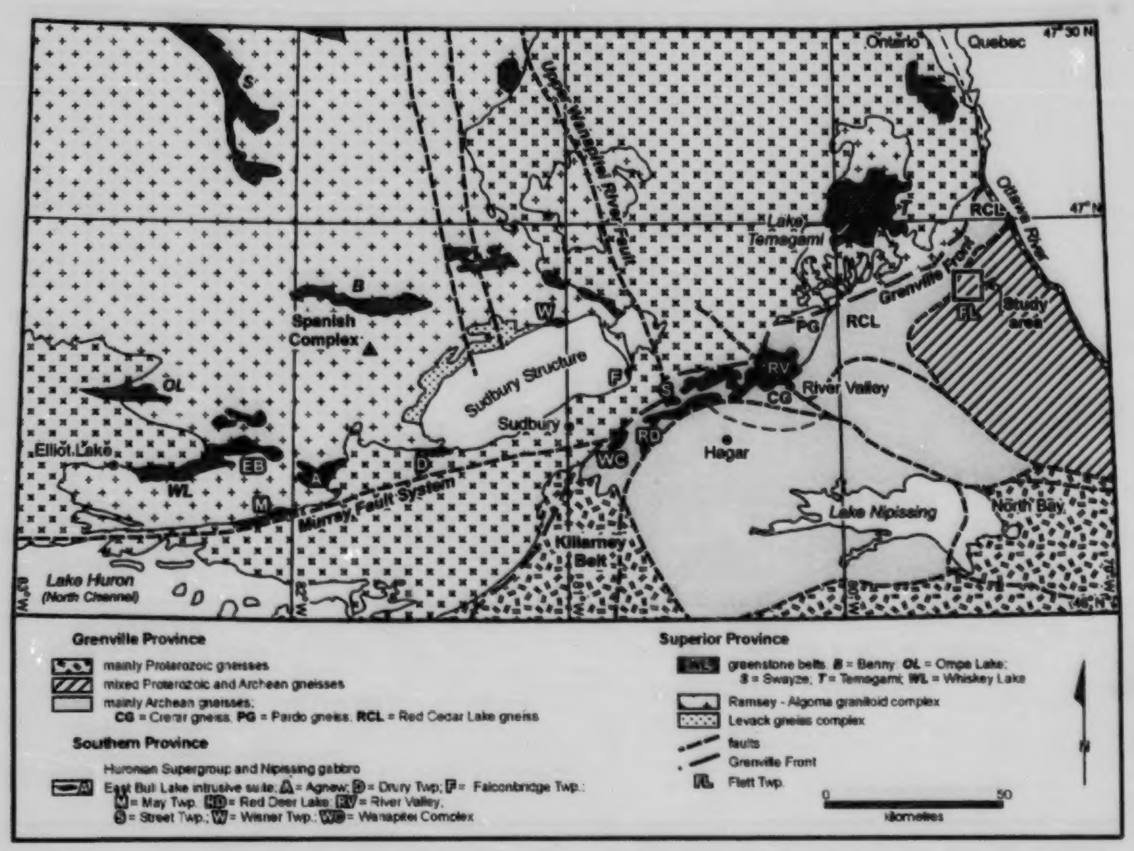
Ontario
Quebec
47° 30' N
47° N
46° N
S
B
Spanish Complex
OL
Elliot Lake
EB
WL
M
A
D
Murray Fault System
Upper Wanapitei River Fault
W
Sudbury Structure
Sudbury
F
S
WC
RD
RV
CG
River Valley
Hagar
Lake Temagami
T
RCL
PG
Grenville Front
Ottawa River
FL
Study area
Lake Nipissing
North Bay
Killarney Belt
Lake Huron (North Channel)
Grenville Province
mainly Proterozoic gneisses
mixed Proterozoic and Archean gneisses
mainly Archean gneisses; CG = Crerar gneiss, PG = Pardo gneiss, RCL = Red Cedar Lake gneiss
Southern Province
Huronian Supergroup and Nipissing gabbro
East Bull Lake intrusive suite; A = Agnew; D = Drury Twp; F = Falconbridge Twp.; M = May Twp. RD = Red Deer Lake; RV = River Valley, S = Street Twp.; W = Wisner Twp.; WC = Wanapitei Complex
Superior Province
greenstone belts, B = Benny, OL = Ompa Lake; S = Swayze; T = Temagami; WL = Whiskey Lake
Ramsey - Algoma granitoid complex
Levack gneiss complex
faults
Grenville Front
FL Flett Twp.
0
50
kilometres
N

Figure 23.1. Location map showing the location of the study area, the distribution of the Archean rocks in the south-central Canadian Shield in Ontario, and the distribution of rocks of the East Bull Lake intrusive suite. *Modified from* Easton (2000).

FANNY LAKE INTRUSION

Country Rocks

The area west of the Fanny Lake intrusion is underlain by rocks of the Red Cedar Lake gneiss (Lumbers 1978; Easton 1992) (*see* Figures 23.2 and 23.3), a regionally extensive unit that crops out within the Grenville Front tectonic zone between River Valley and the Ottawa River (*see* Figure 23.1). The unit is highly flattened near the contact of the Fanny Lake intrusion, but exhibits a less intense flattening fabric to the west. The Red Cedar Lake gneiss consists mainly of a granular, granodioritic gneiss, that locally contains abundant inclusions of fine-grained quartzofeldspathic gneiss (metawacke). Regional structural fabrics are dominantly north trending. The Red Cedar Lake gneiss has been interpreted (Lumbers 1978; Easton 1992, 2000) as representing migmatized greywackes and associated granodioritic intrusive rocks of Neoarchean age that have been overprinted by Grenvillian metamorphism.

The area north, south and east of the Fanny Lake intrusion is underlain by granitic gneiss, locally containing belts of biotite-hornblende diorite gneiss and mafic gneiss (*see* Figure 23.2), and small areas of recognizable metasedimentary rocks. Structural fabrics in the gneisses are dominantly north trending.

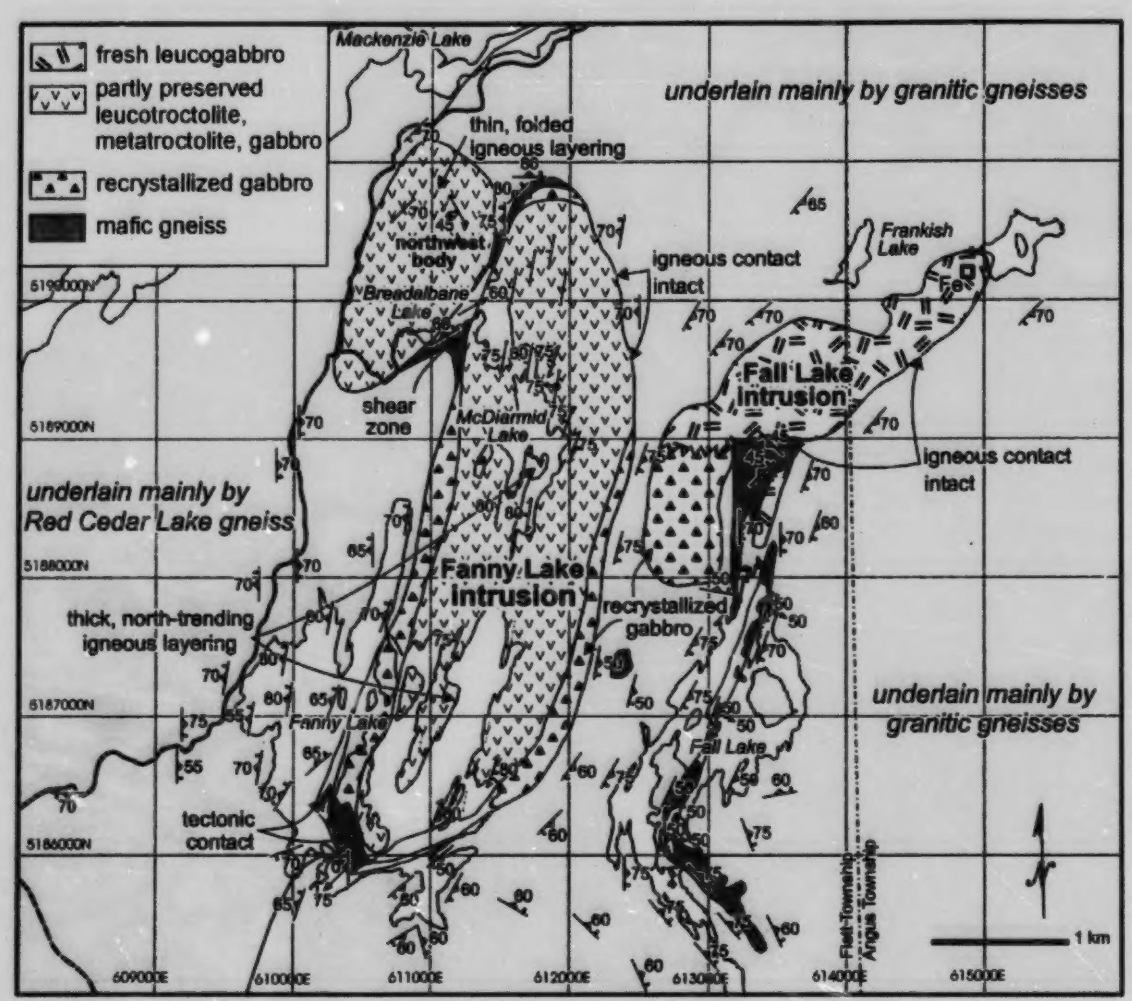
fresh leucogabbro
partly preserved leucotroctolite, metatroctolite, gabbro
recrystallized gabbro
mafic gneiss
Mackenzie Lake
thin, folded igneous layering
underlain mainly by granitic gneisses
northwest body
Breadalbane Lake
igneous contact intact
Frankish Lake
Fe
Fall Lake intrusion
shear zone
McDiarmid Lake
underlain mainly by Red Cedar Lake gneiss
Fanny Lake intrusion
recrystallized gabbro
thick, north-trending igneous layering
Fanny Lake
Fall Lake
underlain mainly by granitic gneisses
tectonic contact
Flett Township
Argus Township
1 km
5190000N
5189000N
5188000N
5187000N
5186000N
609000E
610000E
611000E
612000E
613000E
614000E
615000E

Figure 23.2. Sketch map showing key features of the Fanny and Fall Lake intrusions. Structural symbols are the same as those used in Figure 23.3.

Along the southern margin of the Fanny Lake intrusion, a previously undocumented, 1 km long, belt of metaconglomerate was identified (*see* Figure 23.3). Several varieties of metaconglomerate are present, including 1) a heterogeneous, matrix-supported metaconglomerate (Figure 23.5a); 2) a matrix-supported metaconglomerate dominated by granitoid clasts in a feldspathic matrix; and 3) a clast-supported metaconglomerate dominated by granitic clasts that grades into adjacent gneissic granite. It is possible that this gradation represents a preserved unconformity.

Immediately to the south of the intrusion are quartzose schists that probably represent metamorphosed feldspathic arenites. The quartzose schists and metaconglomerates were not observed in contact with one another. The age of the metaconglomerates and the quartzose schists is unknown. They could be correlative with Huronian Supergroup metasedimentary rocks, immediately to the north along the Grenville Front (Gowganda and Lorrain formations). Alternatively, they could be correlative with quartzite of Geon 16 age, found approximately 20 km to the south-southeast, in the Tomiko domain of the Grenville Province.

Contact Relationships and Geophysical Expression

A northeast-striking shear zone in mafic gneiss is exposed on islands in Breadalbane Lake and divides the Fanny Lake intrusion into a northwest body (*see* Figure 23.2) and a main body. This shear zone may connect with a major north-northeast-trending deformation zone that is parallel to Wicksteed Lake, southwest of the study area. The flattening fabric observed in the Red Cedar Lake gneiss may be a manifestation of this shear zone. The northwest body stands topographically higher than the main lobe of the intrusion and, in general, all rocks of the intrusion stand topographically higher than the country rocks. The intrusion is best exposed along the shores of Fanny and McDiarmid lakes, and in the northern half of the northwest body. Elsewhere, the intrusion is poorly exposed and access is hampered by dense bush throughout the township.

Country rocks and mafic intrusive rocks of the Fanny Lake intrusion occur within a few metres of one another, however, no contacts were observed. Relatively sharp contacts with no indication of shearing and only minor recrystallization of the mafic intrusive rocks are present along the northern margin of the northwest body and the northeast margin of the main body. Contacts in these areas likely represent preserved intrusive contacts (*see* Figure 23.2). In contrast, the northern, southern, and western margins of the main body of the Fanny Lake intrusion consist of 1) an inner rim—tens to hundreds of metres thick—of recrystallized gabbro (dominated by fine-grained amphibole and plagioclase); and 2) an outer rim—tens to hundreds of metres thick—of mafic gneiss, typically strongly lineated and locally garnet-bearing (*see* Figures 23.2 and 23.3). Although deformed and recrystallized along its margins, the interior of the body is relatively undeformed and exhibits very few outcrop-scale shear zones. The intrusive rocks show no indication of increased deformation adjacent to topographic lows or lineaments.

Aeromagnetic and Bouguer gravity highs (Ontario Geological Survey 1991a, 199b, 1991c; Terraquest 1999) are associated with the Fanny Lake intrusion. The aeromagnetic data also shows the presence of a northwest lobe separated from the main body by a magnetic low. The southwestern margin of the northwest body, delineated by bedrock mapping, extends several hundred metres south of the magnetic anomaly. Contacts delineated by bedrock mapping and contacts between aeromagnetic and Bouguer gravity anomalies correspond fairly closely with interpreted intrusive contacts. In contrast, the contacts between aeromagnetic and Bouguer gravity anomalies extend several hundred metres further west than the western geological contact delineated by bedrock mapping. The aeromagnetic data indicates the presence of a north-trending magnetic fabric in the main body that appears to correspond with the trend of igneous layering (Terraquest 1999) (*see* Figures 23.3 and 23.5b).

Mafic Intrusive Rocks and Stratigraphy

Five main rock types, all variably metamorphosed, are present in the Fanny Lake intrusion (*see* Figure 23.3). As noted above, two of these, namely recrystallized gabbro and mafic gneiss, occur within the margin of the body and were likely derived from the other three types. The other three rock types preserve igneous textures and layering, however, olivine and/or orthopyroxene in these rocks develop coronas, indicating that they were subjected to regional metamorphism. Leucotroctolite accounts for roughly 40% of the surface area of the intrusion (*see* Figure 23.5b), with troctolite and melatroctolite (*see* Figure 23.5c) each accounting for another 20%. Troctolitic rocks typically contain minor amounts of pyroxene (<10%). Some of the melatroctolites approach dunite in composition (i.e., <10% plagioclase), but are dominated by magnetite, not chromite, as the oxide phase. Brecciated, gossanous or sulphide-bearing rocks were not observed by the author within the Fanny Lake intrusion.

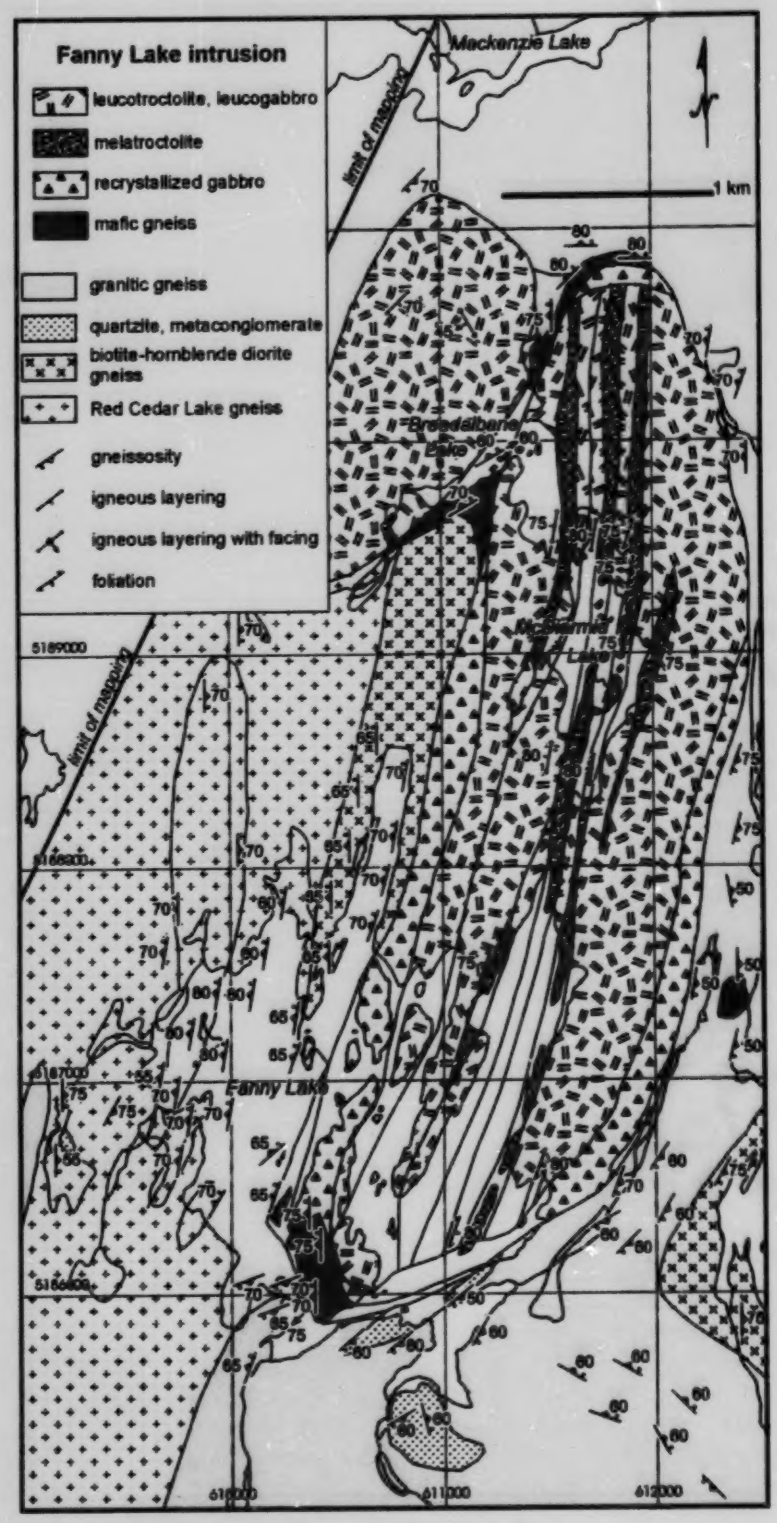
Fanny Lake intrusion
leucotroctolite, leucogabbro
melatroctolite
recrystallized gabbro
mafic gneiss
granitic gneiss
quartzite, metaconglomerate
biotite-hornblende diorite gneiss
Red Cedar Lake gneiss
gneissosity
igneous layering
igneous layering with facing
foliation
Mackenzie Lake
limit of mapping
1 km
Breadalbane Lake
McGuinnis Lake
Fanny Lake
5189000
5188000
5187000
5186000
610000
611000
612000

Figure 23.3. Simplified geological map of the Fanny Lake intrusion.

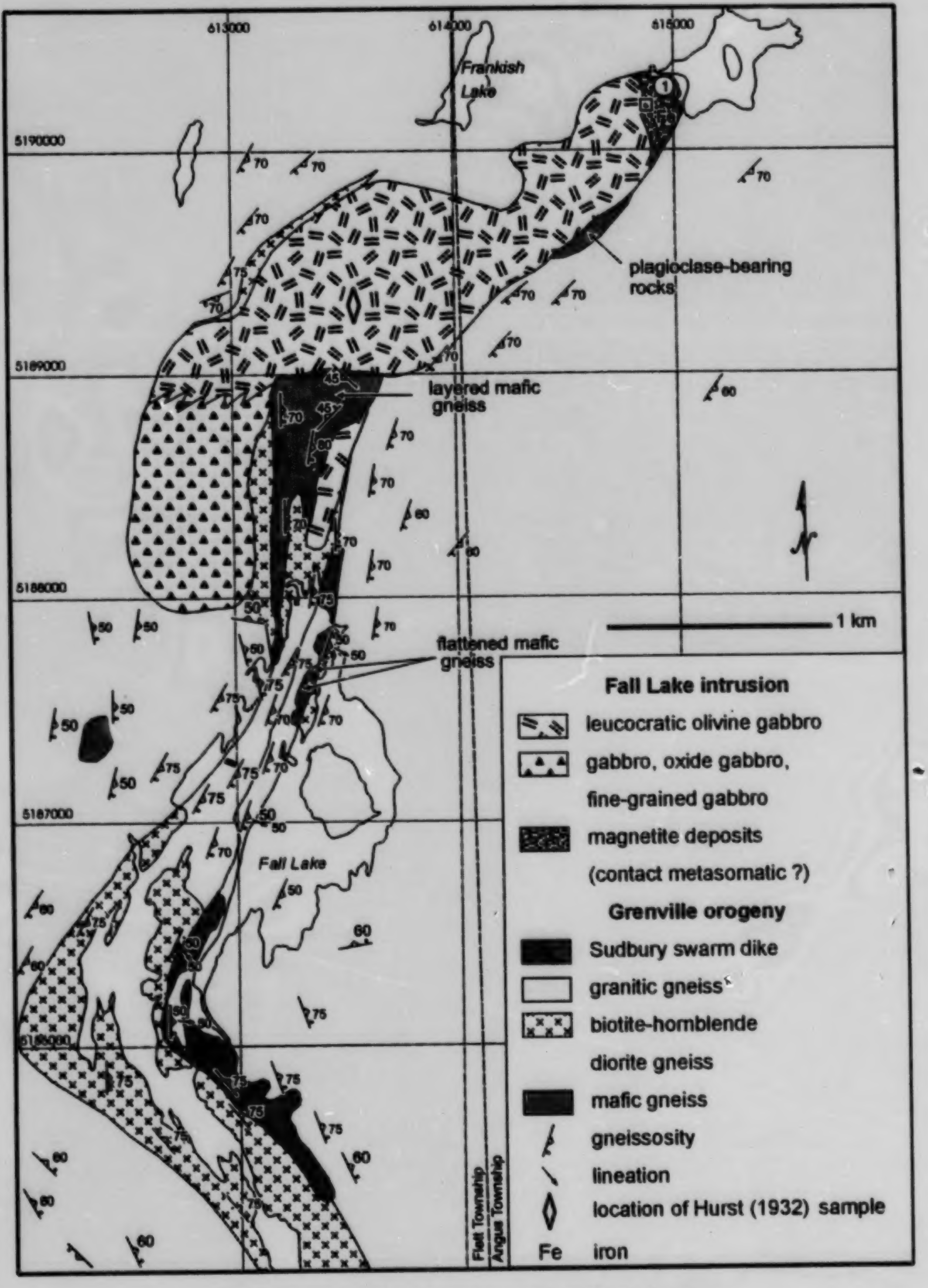
613000
614000
615000
5190000
5189000
5188000
5187000
5186000
Frankish Lake
Fall Lake
plagioclase-bearing rocks
layered mafic gneiss
flattened mafic gneiss
1 km
Flat Township
Angus Township
Fall Lake intrusion
leucocratic olivine gabbro
gabbro, oxide gabbro, fine-grained gabbro
magnetite deposits (contact metasomatic ?)
Grenville orogeny
Sudbury swarm dike
granitic gneiss
biotite-hornblende diorite gneiss
mafic gneiss
gneissosity
lineation
location of Hurst (1932) sample
Fe iron

Figure 23.4. Simplified geological map of the Fall Lake intrusion.

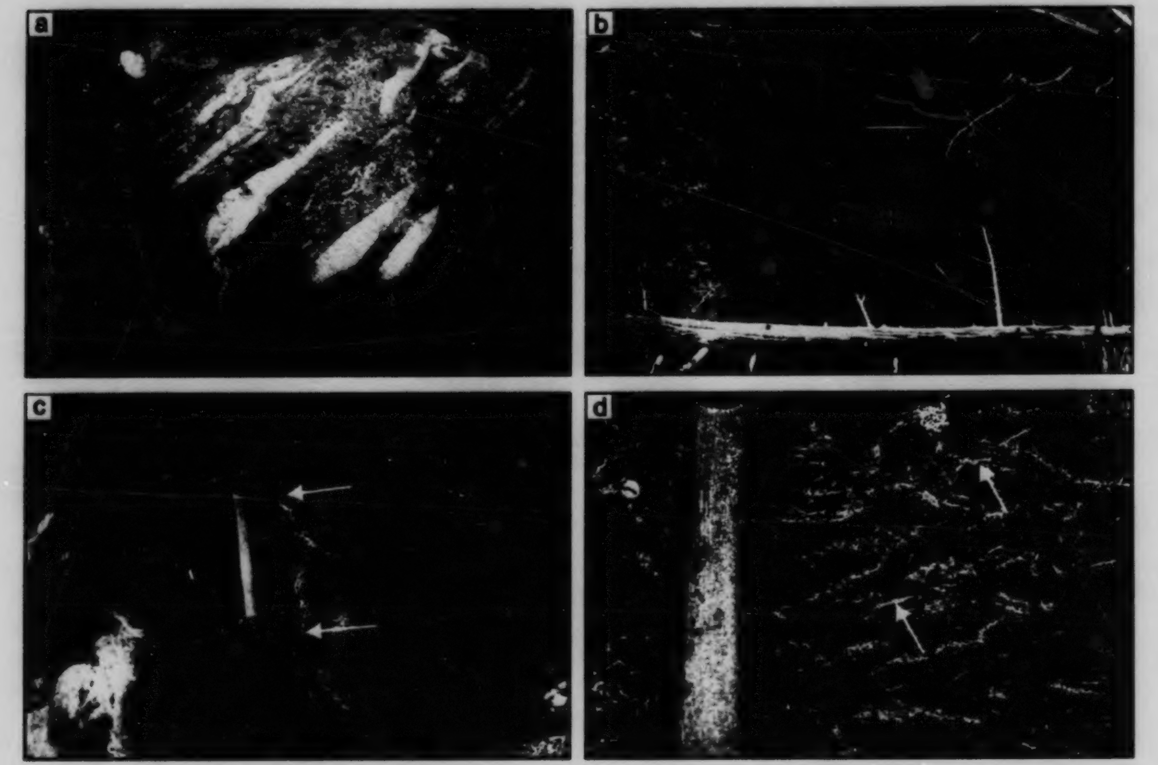

Figure 23.5. **a)** Flattened metaconglomerate, southern Fanny Lake. UTM 610770E, 5185895N. **b)** Decametre-scale, north-trending, igneous layering in the Fanny Lake intrusion, northern McDiarmid Lake. UTM 611838E, 5189258N. **c)** Arrows point to alteration veins consisting of magnetite and iron-rich clay minerals within melatroctolite of the Fanny Lake intrusion, southern McDiarmid Lake. UTM 611719E, 5188950N. **d)** Development of large secondary plagioclase laths (shown by arrows) in mafic gneiss located within 10 m of the contact of the Fall Lake intrusion. UTM 614618E, 5189639N. All UTM co-ordinates are in zone 17T, NAD 83. Hammer handle is 30 cm long.

In the main body, compositional layering (50 to 250 m thick) is defined by variation in olivine content. In some layers, mineral grading or cross-bedding provide some indication of facing direction. In the main body, this layering is oriented between 180° and 200°, and is generally steeply west-dipping and facing (*see* Figures 23.5b and 23.3). Limited measurements from the poorly exposed eastern part of the main body indicates a reversal in dip to the east (*see* Figure 23.3), which could indicate that layering is folded around a north-trending anticline. If the intrusion is not folded, then approximately 1 km of stratigraphy is exposed in the body, consisting, from west to east, of the following sequence:

>150 m	troctolite
75–250 m	leucotroctolite, layered
75 m	melatroctolite, strongly veined and/or foliated
150 m	leucotroctolite
75 m	melatroctolite, strongly veined
75–150 m	leucotroctolite, layered
75–150 m	melatroctolite, foliated
150 m	leucotroctolite
75–100 m	melatroctolite, foliated
>250 m	leucotroctolite

In addition to west to east variation, there may also be thickening, thinning and interdigitation of layers in a north to south direction (*see* Figure 23.3). It is not possible to reliably determine the top or bottom of the intrusion, however, if the intrusion is not folded, then the few facing directions would suggest that the eastern contact of the intrusion might be the base of the main body. If the intrusion is folded, then the olivine-rich rocks at McDiarmid Lake and eastern Fanny Lake would represent the basal part of the intrusion.

The northwest body consists mainly of leucotroctolite with minor troctolite and melatroctolite. Layering in the northwest body is also defined by variation in olivine content, however, layers are thinner (decametre to metre scale) than those observed in the main body. The trend of the layering suggests folding about a northeast-trending synform (*see* Figure 23.3).

Melatroctolite layers, in the main body, typically show a north-striking foliation, parallel to unit contacts. The layers are commonly cut by alteration veins consisting of fine-grained white to black orange rock containing layers and pods of medium-grained magnetite (*see* Figure 23.5c). Alteration vein density can vary from less than 15% of the outcrop surface to more than 50%, and the veins are always more oxide rich than the host melatroctolite. Previously noted iron occurrences in the Fanny Lake intrusion (Lumbers 1971a) are located in these melatroctolite layers, and most likely correspond to areas of more intense alteration.

Age Relationships

A pre-Grenvillian age for the Fanny Lake intrusion is indicated by the fact that 1) it is cut by a shear zone that also affects other Grenvillian units; 2) intense metamorphic recrystallization and deformation affects rocks of the intrusion, especially along its northern, southern and western margins; and 3) rocks hosting preserved igneous textures and layering within the core of the intrusion contain metamorphic coronas around olivine and/or orthopyroxene grains.

There is no clear indication of the tectonic affinity or age of the Fanny Lake intrusion, however, it differs from the East Bull Lake intrusive suite in several key respects (*see* Table 23.1):

1. Limited geochemical data (Racicot and Keevil 1998) indicate that it is characterized by rocks having TiO_2 contents greater than 0.75 weight %, whereas rocks of the East Bull Lake intrusive suite generally have TiO_2 contents less than 0.5 weight % (James et al., in press).
2. It consists mainly of olivine-dominated (troctolite, leucotroctolite) rather than orthopyroxene-dominated (norite, leuconorite, gabbronorite) rocks.
3. Olivine in the intrusion is fayalitic (iron rich), whereas olivine present in the East Bull Lake intrusive suite is forsteritic (magnesium rich) (James et al., in press).
4. The stratigraphy of the intrusion differs from that found in intrusions of the East Bull Lake intrusive suite (James et al., in press).
5. The style of deformation present within the intrusion differs from that observed in the River Valley intrusion (James et al., in press), which is also found within the Grenville Front tectonic zone. Even the relatively well-preserved parts of the River Valley intrusion show the presence of numerous small-scale shear zones and intense deformation and recrystallization is commonly observed at the edges of outcrops, especially adjacent to topographic lows and lineaments. In contrast, apart from the margin of the Fanny Lake intrusion, there is minimal evidence of intense deformation or recrystallization in its core.

These differences between the Fanny Lake intrusion and the East Bull Lake intrusive suite suggest that these intrusions are different ages. A sample from the leucotroctolite phase of the Fanny Lake intrusion was collected for U/Pb geochronology to test this hypothesis.

Assay Data

Assay data from the Fanny Lake intrusion is summarized in Table 23.2. No significant mineralization was noted in samples collected by the author, which encompass all major units of the intrusion. Previous exploration work on the intrusion that focussed on platinum group element (PGE) mineralization also reported low values for Cr, Ni, Cu, Pd and Pt (Racicot and Keevil 1998).

FALL LAKE INTRUSION

Country Rocks

Country rocks consist mainly of fine- to medium-grained, monzo- and syenogranite gneiss. The granitic gneiss locally incorporates rafts and screens of granodioritic to tonalitic gneiss east of Fall Lake. The granitic gneiss locally incorporates rafts and screens of biotite-rich quartzofeldspathic gneiss and mafic gneiss west of Fall Lake.

A northerly tending belt of biotite-hornblende diorite gneiss and mafic gneiss extends through Fall Lake (*see* Figure 23.4). The mafic gneisses are extremely flattened and lineated on Fall Lake and range in composition from gabbro to leucogabbro. In terms of texture and deformation state, the mafic gneiss resembles the gneissic portions of the River Valley intrusion. As with the Fanny Lake intrusion, these mafic gneisses are bounded to the west by a medium-grained biotite-hornblende diorite to quartz diorite gneiss. North of Fall Lake, the mafic gneiss unit is less deformed and exhibits compositional layering which is tightly folded (*see* Figure 23.4). This folded compositional layering is truncated by leucocratic olivine gabbro of the Fall Lake intrusion. Lumbers (1971a, 1971b) included the mafic gneiss and the biotite-hornblende diorite gneiss with the Fall Lake intrusion, showing them as a deformed marginal phase of the intrusion. Based on the degree of deformation, and the crosscutting contact relationships noted above, the mafic gneiss and the diorite gneiss are interpreted to be older than the Fall Lake intrusion. It is unclear whether or not these mafic gneisses are related to the East Bull Lake intrusive suite or whether they are similar in age to the Fanny Lake intrusion.

Adjacent to the northeast contact of the Fall Lake intrusion, mafic gneiss contains 1 to 3 cm long plagioclase laths (*see* Figure 23.5d) in a zone up to 50 m wide near the contact. The plagioclase laths are oriented parallel to the contact, and also occur in the olivine gabbro immediately adjacent to the contact. The presence of these laths is interpreted to be a result of a contact metamorphic effect of the intrusion.

Table 23.1. Chart comparing the key features of the Fanny and Fall Lake intrusions with the River Valley intrusion (East Bull Lake intrusive suite) and rocks of the Sudbury dike swarm. Sources: this study, James et al. (in press).

Age	Chemical Affinity	Rock Types	Primary Textures	Metamorphic Textures & Facies	Deformation	Mineralization	Au+Pd+Pt background values	Olivine composition	Plagioclase composition
Fanny Lake intrusion									
>1070 Ma	Within-plate and low-K tholeiite, slightly alkalic, Mg# 69–58	Melatroctolite, troctolite, leucotroctolite; stratigraphic section present, but sequence not yet established	Igneous layering and textures preserved	Coronas around olivine, in margins of body, replacement of mafic minerals by amphibole & garnet, development of mafic gneiss; upper amphibolite	Around edges of intrusion	Magnetite in veins in melatroctolite	<8 ppb	Fo_{41-56}	An_{64-81}
Fall Lake intrusion									
<2475 Ma, may be <1000 Ma	Within-plate tholeiite, slightly alkalic	Gabbro, olivine gabbro, leucocratic olivine gabbro	Igneous textures preserved	In SW lobe, replacement of mafic minerals by amphibole; middle amphibolite in SW lobe	Minimal in intrusion	Fe-T-V magnetite ore body, ilmenite main oxide phase	<8 ppb	Fo_{24-31}	An_{61-64}
River Valley intrusion									
2475±2 Ma	High-alumina tholeiitic basalt, Mg# 78–43, average 60–65	Gabbronorite, norite, olivine norite, minor noritic anorthosite, stratigraphy from base to top is: marginal zone, inclusion-bearing zone, olivine gabbronorite zone, gabbronorite zone, leucogabbronorite zone	Igneous layering and textures preserved	Coronas around olivine & orthopyroxene, margins, replacement of mafic minerals by amphibole & garnet, development of mafic gneiss; upper amphibolite	Throughout intrusion, better preserved parts stand topographically high and are deformed along margins, less preservation with increasing distance from Grenville Front	PGE+Cu sulphides in inclusion-bearing rocks near margin of intrusion, magnetite is main oxide phase	35–40 ppb	Fo_{64} Fo_{72-76}	An_{68-73} An_{62-78} An_{58-75} An_{58-63}
Sudbury dike swarm									
1238±4 Ma	Within plate tholeiite or volcanic arc basalt, alkalic, high Ba, Mg# 45–35	Olivine gabbro	Chill margins, igneous textures	Coronas around olivine & pyroxene, garnet develops in chill margins; upper amphibolite	Increases with increasing distance from Grenville Front	No significant mineralization reported	<8 ppb	Fo_{26-33}	An_{60}

Table 23.2. Assay data for rocks from Flett and Angus townships. Detection limit for each element is listed in brackets under that element. Eastings and northings are in UTM zone 17T, NAD 83. All analyses except Hurst (1932) performed at the Geoscience Laboratories, Ontario Geosciences Centre, Sudbury.

Sample No.	Easting	Northing	Rock Type	Au (5 ppb)	Co (5 ppm)	Cu (5 ppm)	Ni (5 ppm)	V (5 ppm)	Pd (8 ppb)	Pt (8 ppb)
Fanny Lake intrusion										
01RME-0140	610556	5187061	Rx gabbro	ND	30	ND	14	ND	ND	ND
01RME-0142	610554	5186635	Rx melanogabbro	ND	82	ND	18	341	ND	ND
01RME-142-2	610586	5186640	Rusty boulder	ND	43	ND	17	321	ND	ND
01RME-0143	610600	5186298	Leucotroctolite	ND	83	31	263	44	ND	ND
01RME-0144	610715	5186004	Gneissic gabbro	ND	50	18	159	57	ND	ND
01RME-0166	610300	5186130	Gneissic gabbro	ND	ND	74	41	200	ND	ND
01RME-0180	610910	5187010	Leucotroctolite	ND	67	18	207	107	ND	ND
01RME-0188	611591	5188610	Leucotroctolite	ND	77	11	306	47	ND	ND
01RME-0190	611572	5189022	Olivine gabbro	ND	59	23	150	73	ND	ND
01RME-0191	611630	5189340	Leucotroctolite	ND	96	ND	403	ND	ND	ND
01RME-0195	611777	5189362	Olivine gabbro	ND	187	ND	935	34	ND	ND
01RME-0199	611984	5188956	Olivine gabbro	ND	188	ND	518	41	ND	ND
01RME-0216	611230	5186510	Olivine gabbro	ND	139	ND	680	34	ND	ND
01RME-0217	611089	5186188	Olivine gabbro	ND	183	7	840	46	ND	ND
01RME-0225	611227	5187403	Olivine gabbro	ND	134	9	568	22	ND	ND
01RME-0230	611062	5186836	Leucotroctolite	ND	120	12	380	57	ND	ND
01RME-0251	611719	5188950	Olivine gabbro	ND	128	ND	659	10	ND	ND
01RME-0256	611190	5188996	Olivine gabbro	ND	81	111	37	321	ND	ND
01RME-0267	611580	5189850	Olivine gabbro	ND	101	ND	335	27	ND	ND
01RME-0268	611607	5189654	Olivine gabbro	ND	104	ND	329	43	ND	ND
01RME-0281	610875	5190668	Olivine gabbro	ND	132	ND	583	8	ND	ND
01RME-0284	611488	5187777	Olivine gabbro	ND	186	ND	912	20	ND	ND
01RME-0292	612276	5190319	Olivine gabbro	ND	103	ND	281	126	ND	ND
01RME-0307	611330	5190653	Leucotroctolite	ND	83	11	288	40	ND	ND
01RME-0313	611550	5188614	Leucotroctolite	ND	64	25	186	97	ND	ND
01RME-0314	611550	5188614	Leucotroctolite	ND	123	25	456	59	ND	ND
Fall Lake intrusion										
01RME-0066	612678	5188162	Gabbro	ND	77	96	33	118	ND	ND
01RME-0067	612630	5188300	Ol leucogabbro	ND	94	86	58	227	ND	ND
01RME-0068	612762	5188221	Gabbro	ND	42	21	14	40	ND	ND
01RME-0070	612931	5188000	Gabbro	ND	46	20	13	19	ND	ND
01RME-0071	612900	5188063	Gabbro	ND	48	24	13	16	ND	ND
01RME-0072	612880	5188087	Gabbro	ND	39	6	14	19	ND	ND
01RME-0075	613000	5188327	Fgr amphibolite	ND	79	ND	22	74	ND	ND
01RME-0076	613052	5188708	Gabbro	ND	64	30	18	176	ND	ND
01RME-0078	612891	5188980	Gabbro	ND	54	37	20	94	ND	ND
01RME-0079	612950	5189213	Gabbro	ND	48	32	19	88	ND	ND
01RME-0081	612682	5188689	Gabbro	ND	68	80	42	182	ND	ND
01RME-0101	613013	5189100	Ol leucogabbro	ND	55	21	23	96	ND	ND
01RME-0106	613663	5189800	Ol leucogabbro	ND	68	52	46	144	ND	ND
01RME-0113	613593	5189242	Ol leucogabbro	ND	50	123	22	93	ND	ND
01RME-0119	613417	5188293	Ol leucogabbro	ND	42	13	14	45	ND	ND
01RME-0121	614185	5189650	Ol leucogabbro	ND	57	20	49	168	ND	ND
01RME-121-2	614185	5189650	Ol leucogabbro	ND	62	20	57	213	ND	ND
01RME-0124	614861	5190116	Ol leucogabbro	ND	84	29	96	546	ND	ND
Host Rocks										
01RME-0008	612977	5187253	Gabbro	ND	13	ND	11	ND	ND	ND
01RME-0032	612985	5186643	Mafic gneiss	ND	98	29	76	504	ND	ND
01RME-0033	612844	5186450	Mafic gneiss	ND	51	22	36	227	ND	ND
01RME-0046	612920	5187060	Bi-hb diorite gneiss	ND	14	ND	9	ND	ND	ND
01RME-0058	612378	5187395	Mafic gneiss	ND	62	48	102	167	ND	ND
01RME-0102	613034	5189255	Bi-hb diorite gneiss	ND	48	23	34	89	ND	ND
01RME-0128	614618	5189639	Mafic gneiss	ND	92	48	101	425	ND	ND
01RME-0150	610792	5185535	Quartzose schist	ND	ND	ND	ND	25	ND	ND
01RME-0170	610840	5188322	Bi-hb diorite gneiss	ND	14	ND	11	ND	ND	ND
O'Connor magnetite occurrence				**Fe** (wt %)	**Co** (ppm)	**Cu** (ppm)	**Ni** (ppm)	**V** (ppm)	**TiO_2** (wt %)	**Au, Pd & Pt**
01RME-0125	614861	5190221	Magnetite ore	–	296	–	337	2680	–	ND
Hurst (1932)	614860	5190220	Magnetite ore	NA	NA	43.62	NA	1800	21.96	NA

Abbreviations: NA, not analyzed; ND, not detected; bi, biotite; fgr, fine grained; hb, hornblende; ol, olivine; rx, recrystallized.

Mafic Intrusive Rocks

The intrusion consists of a main, teardrop-shaped mass north of Fall Lake and a smaller, north-trending dike-like body southeast of the larger body (*see* Figure 23.4). The intrusion stands topographically higher than the country rocks, and supports a distinctive, fern-alder-birch vegetative cover. Four main rock types were observed in the field, from most to least abundant, these are 1) a medium-grained leucocratic olivine gabbro, which was the phase sampled by Hurst (1932); 2) a medium-grained gabbro; 3) a medium-grained olivine gabbro; 4) and a dark weathering, fine-grained gabbro, now amphibolite. These phases are variably weathered, particularly the olivine gabbros.

The southwest part of the main mass (*see* Figure 23.4) shows the most lithologic variation, however, outcrop in this area is sparse and was insufficient to determine the relationships between these different phases (i.e., are they layers within the body or crosscutting phases, etc.?). The southwest lobe is dominated by gabbroic rocks that appear fresh on weathered surfaces, but in thin section show partial or complete replacement of clinopyroxene and olivine by fine-grained amphibole. The fine-grained character and radiating habit of the amphibole is similar to that found in other mafic rocks subjected to Grenville metamorphism, such as the River Valley intrusion, consequently, the amphibole is interpreted to have formed during amphibolite-facies regional metamorphism. Thus, the southwest part of the body has probably been subjected to Grenvillian metamorphism. Preliminary microprobe examination indicates that, in better preserved samples, remnant olivine is iron-rich (Fo_{24-25}), plagioclase is calcic (An_{61-64}), and the oxide phase is ilmenite.

In contrast, the northern part of the main mass, and the dike-like body, consist of leucocratic olivine gabbro to leucotroctolite; in general, this phase is the best exposed portion of the body. In thin section, this rock is fresh, showing no evidence of reaction rims around the mafic minerals. Preliminary microprobe examination indicates that olivine is iron-rich (Fo_{26-31}), clinopyroxene is titaniferous augite, plagioclase is calcic (An_{61-64}), the oxide phase is ilmenite and apatite is a common accessory mineral.

Geophysical Expression

There is less correspondence between the surface geological contacts of the Fall Lake intrusion and aeromagnetic and Bouguer gravity anomalies (Ontario Geological Survey 1991a, 1991b, 1991c) than for the Fanny Lake intrusion. An aeromagnetic high is generally coincident with distribution of the leucocratic olivine gabbro phase of the intrusion (*see* Figure 23.4), with the centre of the anomaly centred near the O'Connor magnetite occurrence, however, the anomaly extends for an additional 1 km west of the intrusion. The Fall Lake intrusion lies within the broad Bouguer anomaly associated with the Fanny Lake intrusion.

Age Relationships

A pre-Grenvillian age for the southwest lobe of the Fall Lake intrusion is indicated by the presence of secondary amphibole replacing primary mafic minerals. The lack of deformation in the southwest lobe, however, may indicate that it was emplaced during the waning stages of the Grenville Orogeny (i.e., between 1090 to 1000 Ma). The age of the leucocratic olivine gabbro that makes up the bulk of the intrusion is more problematic, and it could be post-Grenvillian, based on the following observations.

1. The contact of the leucocratic olivine gabbro apparently truncates both geological contacts and structural trends in the surrounding gneissic rocks (*see* Figure 23.4). These contacts and trends were last modified during the Grenville Orogeny and are interpreted to be older than 1000 Ma.
2. Rocks adjacent to the intrusion, particularly on the northeast margin, appear to have been contact metamorphosed by the intrusion.
3. The carapace of deformed rocks around the intrusion, shown by Lumbers (1971a, 1971b), represent country rocks to the intrusion, and are not tectonized equivalents of the body. This observation is supported by preliminary geochemical results (R.M. Easton, unpublished data, 2001) on both rock types which shows that they are not genetically related.
4. No internal shear zones were observed in the intrusion.
5. The leucocratic olivine gabbro shows less evidence of metamorphism and recrystallization than even the best preserved parts of the Fanny Lake intrusion. This suggests that it is younger than the Fanny Lake intrusion, or that the effects of Grenville metamorphism and deformation decrease eastward with increasing distance from the shear zone that passes through Breadalbane Lake.

In terms of bulk-rock and mineral chemistry, however, rocks of the southwest lobe and the leucocratic olivine gabbro unit are largely indistinguishable. Consequently, it is possible that both parts of the Fall Lake intrusion are similar in age, and that they simply differ in terms of degree of preservation.

The criteria that distinguish the Fall Lake intrusion from rocks of the East Bull Lake intrusive suite are the same as those noted previously for the Fanny Lake intrusion. Mafic gneiss, cut by the Fall Lake intrusion, resemble gneissic phases of the River Valley intrusion and could be correlative with the East Bull Lake intrusive suite. If so, then the Fall Lake intrusion must be younger than the East Bull Lake intrusive suite. A sample of leucocratic olivine gabbro was collected for U/Pb geochronology because it is not clear that the Fanny Lake and Fall Lake intrusions are of similar age.

Assay Data

Assay data from 26 samples of the Fall Lake intrusion and its country rocks are summarized in Table 23.2. Apart from the sample collected from the previously documented O'Connor magnetite occurrence, no significant mineralization was noted in samples collected by the author, which encompass all major phases of the intrusion, as well as mafic gneiss cut by the intrusion. Hurst (1932) attributed the O'Connor occurrence (sometimes referred to as the Titan iron occurrence) to a contact metasomatic origin.

GEOCHEMISTRY

Preliminary geochemical results (R.M. Easton, unpublished data, 2001) indicate some subtle differences between the Fanny and Fall Lake intrusions (Figure 23.6a). Both intrusions are slightly alkalic, lying near or on the tholeiite–alkalic dividing line on most major element discrimination plots. A slightly alkalic character is consistent with the presence of fayalitic olivine and titaniferous augite in both intrusions. On AFM plots, rocks of the Fanny Lake intrusion show a calc-alkalic rather than a tholeiitic differentiation trend. On major and trace element tectonic discrimination diagrams, rocks from the Fanny Lake intrusion show affinities with either low-potassium tholeiites or within-plate basalts, whereas rocks from the Fall Lake intrusion show affinities with within-plate basalts (*see* Figure 23.6a). In CIPW normative calculations, many of the Fall Lake samples are quartz normative, whereas the Fanny Lake samples are not. This is consistent with the slightly higher silica contents observed for the Fall Lake

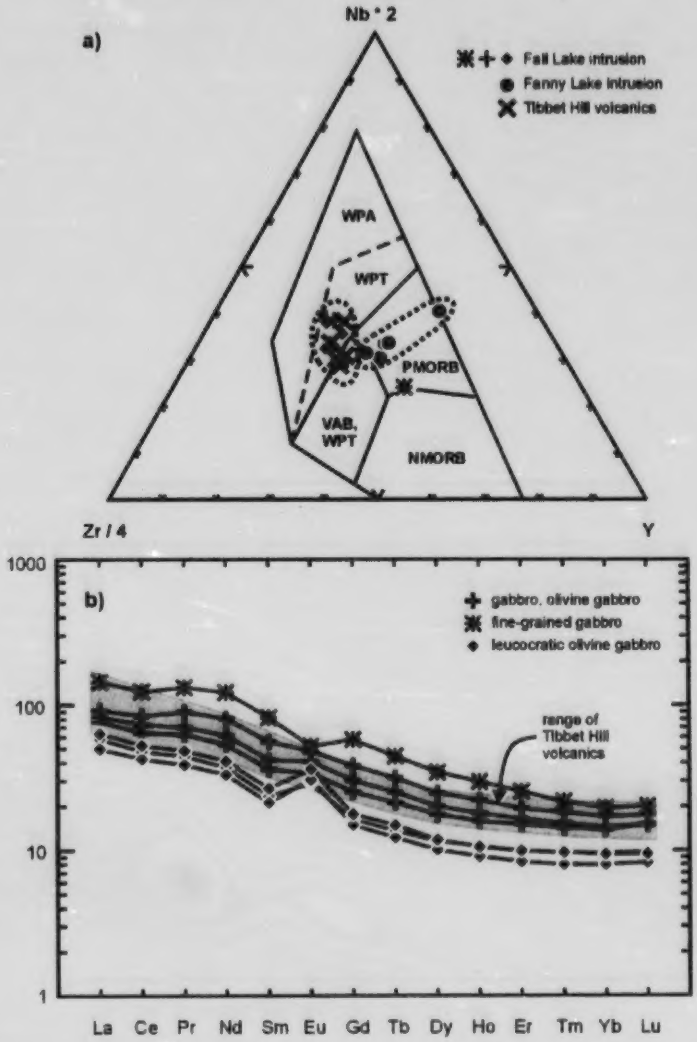

Figure 23.6. a) Zr/4–Nb*2–Y plot (*after* Meschede 1986) for samples of the Fanny and Fall Lake intrusions and the Tibbet Hill volcanics. Abbreviations: N-MORB, normal mid-ocean ridge basalt; P-MORB, primititive mid-ocean ridge basalt; VAB, volcanic-arc basalt; WPT, within-plate tholeiitic basalt. **b)** Chondrite-normalized rare earth element plot for samples of the Fall Lake intrusion. The range of the Tibbet Hill volcanics is shown for comparison. Tibbet Hill data in both plots *from* Pitson, Kumarapeli and Morency (1985).

samples. CIPW normative calculations also suggest that measured anorthite contents of plagioclase (An_{61-64}) from the better preserved parts of the intrusions reflect original compositions and did not decrease during regional metamorphism.

Within the Fall Lake intrusion, 2 chemical groupings are present, which are best distinguished using trace and rare earth elements (*see* Figure 23.6b). One group, consisting of the more mafic phases, is characterized by gently sloping rare earth element patterns with no europium anomaly. The other group, consisting of the leucocratic phases, also has a gently sloping rare earth element pattern, but with lower total rare earth content and positive europium anomalies. The differences between the 2 groups can be attributed to plagioclase accumulation in the leucocratic phases.

The preliminary geochemical data suggests an affinity with some continental flood basalt sequences, for example, the slightly alkalic Picture Gorge basalts of the Columbia River flood basalt province or basaltic rocks of the Tibbet Hill volcanics (circa 570 Ma) present further to the south along the Ottawa graben system (Pitson, Kumarapeli and Morency 1985) (*see* Figures 23.6a and 23.6b). If these intrusions are related to a flood basalt system, or whatever age, then it is unclear as to why only two small intrusions of what would have been an extensive magmatic system are apparently preserved? In addition, it is unclear as to why the intrusions are located where they are, as they do not appear to be at the confluence of any major regional structures.

MINERAL POTENTIAL

Copper-Nickel-Platinum Group Element Mineralization

Current models suggest that the following conditions must be meet for the formation of magmatic copper-nickel-PGE deposits (e.g., Lightfoot and Keays 1995): 1) the presence of sulphur-undersaturated magmas; 2) the presence of high-temperature, high-magnesium magmas, which are typically associated with mantle plumes; 3) sulphur-saturation of a previously sulphur-undersaturated magma, due to the assimilation of sulphide-bearing country rocks, near the site of emplacement of the magma, and 4) the presence of physical traps to catch the sulphide mineral phases.

Unfortunately, most of these conditions may not be present for the Fanny and Fall Lake intrusions. Their slightly alkalic and magnesium-poor character suggests low degrees of partial melting in the mantle source region, which reduces the sulphur-capacity of the magma, possibly to the point of generating a sulphur-saturated magma. Furthermore, if the intrusions were related to a continental rifting event producing flood basalt-type magmatism, then the paucity of other intrusions could indicate that this area was distal to the mantle–plume system responsible for rifting, another condition unfavourable with respect to generating a magmatic sulphide mineral deposit. Thus, the first two conditions, which are critical to generating magmatic copper-nickel-PGE deposits, might not have been met. In addition, the third condition may be absent as well, given the quartzofeldspathic and sulphide-poor nature of the host rocks.

To date, analyses of 44 samples from the Fanny and Fall Lake intrusions have not detected PGEs above the detection limits for these elements (*see* Table 23.2). Nickel contents are generally low, even in olivine-rich rocks, consistent with the iron-rich character of the olivines. No gossan or breccia zones have been reported from either intrusion. These observations, in concert with the fact that these intrusions do not seem to meet the critical conditions for the development of large, magmatic copper-nickel-PGE deposits, would suggest that the copper-nickel-PGE potential of these intrusions is relatively low.

Iron-Titanium-Vanadium and Chromium Mineralization

The presence of the O'Connor titaniferous magnetite occurrence, which contains an estimated 140 million tonnes of 36% Fe and 15.6% TiO_2 (Racicot and Keevil 1998) clearly indicates the presence of magmatic iron-titanium-vanadium mineralization in the Fall Lake intrusion. This occurrence is located near the northeast margin of the intrusion, at the centre of a regional aeromagnetic high, the shape of which does not correspond to the mapped bedrock geology of the intrusion. This occurrence has not been actively explored for more than 40 years.

As noted previously, iron occurrences within the Fanny Lake intrusion are found in association with the melatroctolite layers, and appear to result from serpentinization and alteration of the host rocks resulting in magnetite-rich veins and pods. Deposits formed in this manner are not likely to be of sufficient size to be developed. Lower overall titanium and vanadium contents in samples from the Fanny Lake intrusion suggest that it is less likely to host iron-titanium-vanadium mineralization than the Fall Lake intrusion, however, it may host significant magnetite mineralization.

Chromitite mineralization is unlikely in either intrusion, given the iron-rich character and lower nickel contents of these rocks, as reflected by their olivine compositions.

Building Stone

Proximity to the Ontario Northland Railway, immediately south of Fanny Lake, and an existing access road to the railroad west of Fanny Lake makes it feasible to consider the possible extraction of building stone from Flett Township. As noted by Racicot and Keevil (1998), a test block of leucotroctolite has already been taken from the Fanny Lake intrusion. Leucotroctolite from the Fanny Lake intrusion contains dark feldspars, is not highly jointed, and contains few sulphide or other deleterious minerals. It would polish to produce a stone very similar to the Dana Black stone produced from the River Valley intrusion. The presence of amphibole coronas around olivine grains in the rock, however, would likely restrict usage of such a stone to indoor applications, much the same way that amphibole coronas around orthopyroxene in the River Valley intrusion cause unacceptable weathering of the stone in outdoor environments. Leucocratic olivine gabbro from the Fall Lake intrusion, that lacks such coronas, might be a better prospect, although it is slightly lighter in colour and is further from existing transportation links.

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24. Project Unit 00-101. Summary of Geophysical Projects and Activities

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INTRODUCTION

The following geophysical projects and activities were undertaken in support of the bedrock mapping program of the Precambrian Geoscience Section (PGS):

1. Timmins gravity survey
2. Kapuskasing–Chapleau aeromagnetic survey
3. Red Lake hyperspectral survey
4. Base Mapping program integration
5. Twinning agreement

Several other activities are summarized under "Other Activities". Geophysical projects carried out as part of the Operation Treasure Hunt (OTH) initiative are not summarized in this article as they are well documented in other articles in this publication (Deschamps and Morris, this volume; Reford et al., this volume).

Timmins Gravity Survey

Between February 7 and March 31, 2001, a total of 1855 ground gravity measurements were recorded in the Timmins area (Figure 24.1). The survey was carried out under the Timmins collaborative gravity survey project with the purpose of establishing a regional gravity data set to facilitate the interpretation of deep, large-scale structures that could shed new light on the geology of the Timmins area. The project was led by Placer Dome (CLA) Limited and also involved the Ontario Geological Survey, Natural Resources Canada and Explorers Alliance Corporation. The survey itself was carried out by Abitibi Geophysics Inc. under contract to Placer Dome (CLA) Limited. The responsibilities of each of the contributing organizations are as follows:

- Placer Dome (CLA) Limited: major funding and contract management
- Precambrian Geoscience Section, Ontario Geological Survey (OGS), Ministry of Northern Development and Mines (MNDM): project management, final data publication, and partial funding
- Geodetic Survey Division, Geomatics Canada, Natural Resources Canada: quality assurance, quality control and final data reduction and archiving to the National Gravity Data Base
- Explorers Alliance Corporation: partial funding
- Abitibi Geophysics Inc., Val d'Or, Quebec: data acquisition and field data compilation under contract

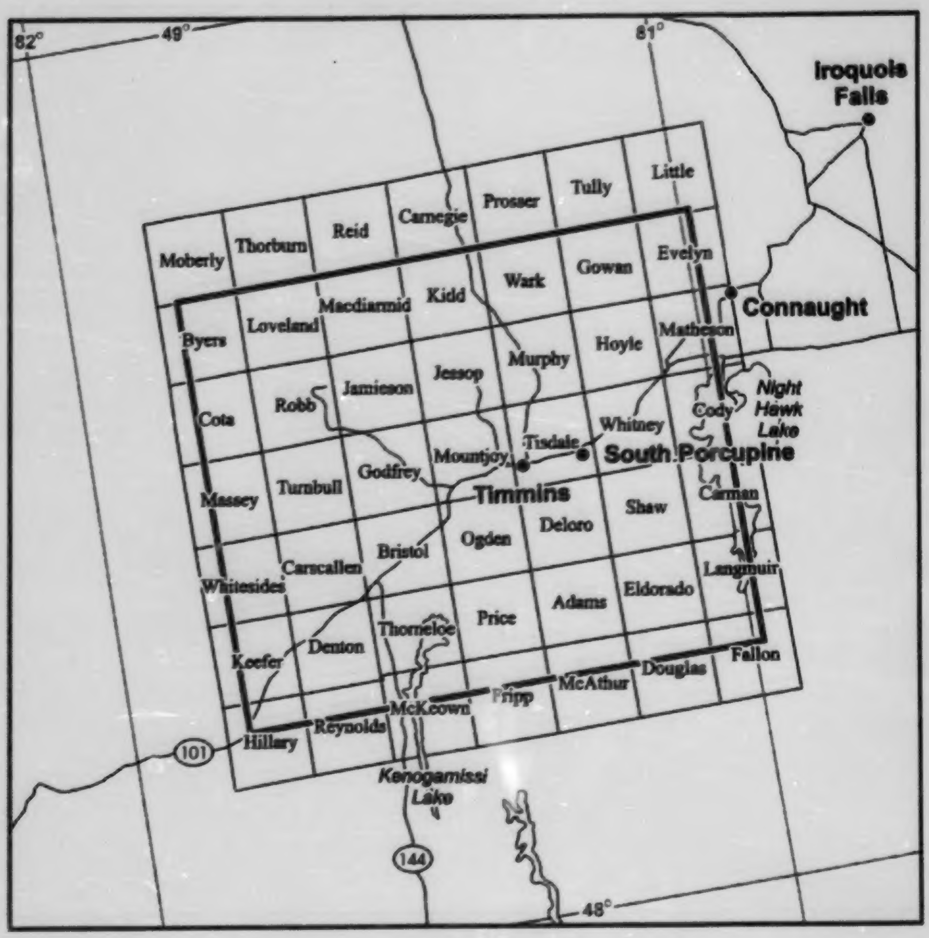
82°
49°
81°
48°
Iroquois Falls
Connaught
Night Hawk Lake
South Porcupine
Timmins
Kenogamissi Lake
101
144
Moberly
Thorburn
Reid
Carnegie
Prosser
Tully
Little
Evelyn
Gowan
Wark
Kidd
Macdiarmid
Loveland
Byers
Matheson
Hoyle
Murphy
Jessop
Jamieson
Robb
Cota
Cody
Whitney
Tisdale
Mountjoy
Godfrey
Turnbull
Massey
Carman
Shaw
Deloro
Ogden
Bristol
Carscallen
Whitesides
Langmuir
Eldorado
Adams
Price
Thorneloe
Denton
Keefer
Fallon
Douglas
McArthur
Fripp
McKeown
Reynolds
Hillary

Figure 24.1. Timmins collaborative gravity survey project: survey location map.

The survey was conducted on a planned 1 km by 1 km grid and measurements were obtained as far as the bush conditions would allow with a reasonable amount of effort. The data were measured using Scintrex CG3 gravity meters and Leica System 500 GPS receivers. The accuracy of the final Bouguer gravity values was 0.17 mGal.

The data are published in both digital and hard-copy formats. The digital data are provided in multiple industry-standard formats in both point data and gridded form. Hard-copy maps of the Bouguer gravity and vertical gravity gradient are available at a scale of 1:100 000. Table 24.1 contains the publication information.

Table 24.1. Summary of new geophysical survey data publications.

Project Name	Product Description	Publication Number
Timmins Collaborative Gravity Survey Project	Digital Ground Gravity Survey Data	Miscellaneous Release—Data 79
Timmins Collaborative Gravity Survey Project	Bouguer Gravity Map @ 1:100 000	Map 81 670
Timmins Collaborative Gravity Survey Project	Vertical Gravity Gradient Map @ 1:100 000	Map 81 671
Kapuskasing–Chapleau Aeromagnetic Survey	Digital Aeromagnetic Survey Data	Geophysical Data Set 1040
Kapuskasing–Chapleau Aeromagnetic Survey	Total Magnetic Field Maps @ 1:50 000	Maps 81 672 through 81 699, inclusive
Kapuskasing–Chapleau Aeromagnetic Survey	First Vertical Derivative of Magnetic Field with Keating Coefficients @ 1:50 000	Maps 81 700 through 81 727, inclusive

Kapuskasing–Chapleau Aeromagnetic Survey

The Kapuskasing–Chapleau aeromagnetic survey comprises 105 848 line kilometres, flown in an area encompassing the communities of Kapuskasing and Chapleau, among others (Figure 24.2). Recognizing the impact that investment in mineral exploration can have on the long-term socio-economic health of communities, FEDNOR, an Industry Canada initiative, funded the data acquisition portion of the survey. The remainder of the project was completed by Geological Survey of Canada, Natural Resources Canada and the OGS, MNDM. The responsibilities of each of the contributing organizations are as follows:

- FEDNOR, an Industy Canada Initiative: funding of aeromagnetic survey data acquisition
- Geological Survey of Canada, Natural Resources Canada: contract and project management, quality assurance, quality control, data processing and compilation, map preparation, publication
- Precambrian Geoscience Section, Ontario Geological Survey, MNDM: digital product preparation, map duplication, publication
- SIAL Geosciences, Montreal, Quebec: data acquisition under contract
- Goldak Exploration, Saskatoon, Saskatchewan: data acquisition under contract
- Scintrex Airborne Systems and Surveys, Toronto, Ontario: data acquisition under contract

The OGS Advisory Board's Technical Committee advises the OGS on geographic areas of interest within Ontario where collection of new data would make the greatest impact on reducing exploration risk. The survey area was selected through this process, with further consultation with industry and under constraints from the airborne industry capacity and time-related factors. The Kapuskasing–Chapleau survey area encompasses a large portion of the Kapuskasing Structural Zone (KSZ) and regions to the west. As the KSZ was the locus of major uplift of Archean crust and upper mantle, it has excellent potential for mineral deposits within rocks units that have tapped these deep-seated magmatic sources such as diamonds in kimberlites and lamprophyres, and phosphates and rare earth metals in carbonatite intrusions. In addition, there may be good potential for platinum group element mineralization, base metals and industrial minerals in mafic intrusions; in anorthosite bodies, such as the Shawmere complex; and within greenstone enclaves (Percival and West 1994).

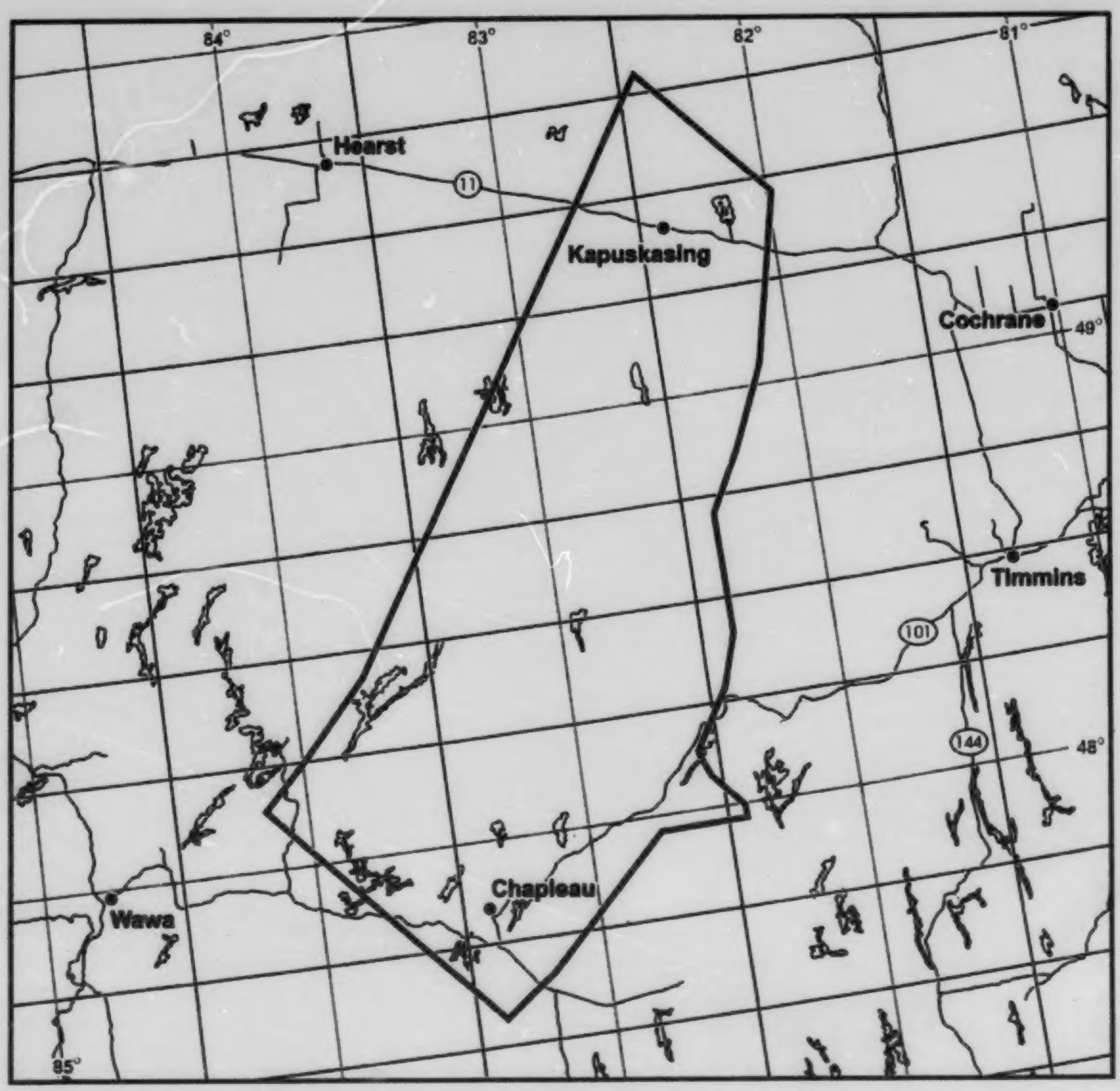

Figure 24.2. Kapuskasing–Chapleau aeromagnetic survey: location map.

The survey was flown with a 200 m line spacing, and a 1600 m control line spacing. The flight line azimuth was 140° and the nominal mean terrain clearance was 100 m. Three airborne survey companies were contracted to complete the data acquisition as specified above.

The data are published in both digital and hard-copy formats. The digital data are provided in multiple industry-standard formats in both line data and gridded form and are accompanied with a survey report. Hard-copy maps of the total magnetic field and first vertical magnetic gradient with Keating correlation coefficients are available at a scale of 1:50 000. Table 24.1 contains the publication information.

The Keating correlation coefficients represent possible kimberlite targets that have been identified from the residual magnetic intensity data, based on the identification of roughly circular anomalies. This procedure was automated by using a known pattern recognition technique (Keating 1995), which consists of computing, over a moving window, a first-order regression between a vertical cylinder model anomaly and the gridded magnetic data. The results are depicted as circular symbols, scaled to reflect the correlation value. The most favourable targets are those that exhibit a cluster of high amplitude solutions. Correlation coefficients with a negative value correspond to sources with a low relative magnetic response. It is important to be aware that other magnetic sources may correlate well with the vertical cylinder model, whereas some kimberlite pipes of irregular geometry may not.

Red Lake Hyperspectral Survey

The OGS is committed to the promotion, advancement and application of new technologies to mineral exploration in Ontario. As part of this commitment, the OGS partnered with the Canada Centre for Remote Sensing (CCRS), Natural Resources Canada, to acquire and publish hyperspectral imaging data collected in the Red Lake greenstone belt in northwestern Ontario. The Red Lake greenstone belt was selected because it has recently been the focus of bedrock mapping (Sanborn-Barrie et al. 2000) and alteration and metallogenic studies (Parker 1999, 2000) carried out under the Western Superior NATMAP initiative (Percival, Breaks et al. 1999; Percival, Bailes et al. 2000). In addition, the area was part of a pilot area for satellite-based engineering terrain studies for the far north (Barnett and Singhroy 2000).

The survey planning was carried out by the CCRS in collaboration with industry and OGS geologists. The data were acquired during August 2001, by R J Burnside and Associates Limited under contract to the CCRS. The data will be processed by the contractor to produce reflectance data. These data will be published by the OGS as a Geophysical Dataset.

Hyperspectral sensors record the spectral response over a portion of the electromagnetic (EM) spectrum by detecting the response over narrow intervals of between 5 and 10 nm. For any given material, the amount of solar radiation that reflects, absorbs, or transmits varies with the wavelength of the solar radiation. For mineral exploration applications, the portion of the spectrum which allows for the best discrimination of minerals from their absorption and reflection characteristics is generally bounded by the infra-red wavelengths of 0.38 and 2.55 µm. The effectiveness of the application of hyperspectral imaging to mineral exploration is Ontario is largely unknown. The challenges that this application faces are many and include the widespread glacial and vegetative cover (including lichen) which restrict the detection of bedrock sources. The hyperspectral survey flown over the Red Lake greenstone belt will hopefully detect the widespread alteration mineral assemblages associated with gold mineralization (Parker 2000).

Support of Precambrian Mapping Projects

The OGS-PGS is committed to the enhancement of the integration of geophysics with ongoing Precambrian bedrock mapping projects. The vision is one in which the geological interpretations will become entirely consistent with the available geophysical data sets and knowledge in the mapping area. Although an ambitious and virtually impossible goal given the complexities inherent in Archean and other geologic terranes, and the reality of limited geophysical resources at the OGS, it sheds light on steps which are required to move toward interpretations which are consistent with all of the available geoscientific data sets.

One clear step is to establish a physical rock properties database to provide the geophysical linkage between the lithology (or other geologic factors such as alteration) and the geophysical data sets—largely airborne—which reflect them. Such a database will facilitate the move from qualitative interpretation of geophysical data sets to quantitative interpretation. Deschamps and Morris (2000; this volume) report on a physical rock properties project being carried out under the Operation Treasure Hunt initiative. The final results of this project and their interpretation will be used to guide further physical rock properties activities to the benefit of the mineral industry and the PGS mapping program.

Six hand-held magnetic susceptibility meters were purchased for use by the PGS geoscientists, beginning in the summer field season of 2001, after an initial test by a PGS field crew during the summer of 2000 (Beakhouse 2000). We expect that OGS geoscientists will benefit from immediate information provided by the meters while interpreting geology on the outcrops, and the longer term benefit of a province-wide magnetic susceptibility database. Early indications suggest that these expectations will be realized. Procedures for the collection and recording of magnetic susceptibility data were established and will be reviewed before the 2002 field season. Data from the hand-held meters will be compared to the results from the OTH physical rock properties project to ensure effectiveness and consistency in the approach to, and reporting of, the physical rock properties information.

Several factors must be considered in determining the best approach to enhancing the use of geophysical information on the various bedrock mapping projects. These factors include

- the types and condition of the geophysical data available
- the effectiveness of the available geophysical data in addressing the perceived geological problems
- the logistics and scope of the project

Based on these factors and considering the current geophysical capacity within the OGS, the ongoing mapping projects for 2001 to 2002 have been categorized as follows:

1. initial examination, interpretation and product preparation of geophysical data, but ongoing support is limited
2. initial examination and interpretation of existing geophysical data, production of useful maps and images, and ongoing support of the field program
3. geophysical data acquisition precedes the mapping program, followed by a workshop-style interpretation of all available geoscientific data, followed by a series of mapping seasons. This would be based on a "New South Wales"-type approach (*see* "Twinning Agreement").

As a result of this categorization, 3 projects were assigned as Category 1, 3 as Category 2 and, given the longer term nature of Category 3, 1 project was assigned to this highest level.

TWINNING AGREEMENT

A twinning agreement (1999) between the OGS and the Geological Survey of New South Wales (GSNSW), Australia, was established to enhance scientific knowledge and application and improve program delivery and impact. A recent visit to the GSNSW by OGS staff has identified the many similarities in purpose and product delivery process, but has highlighted many fundamental differences as well (Reford, Rudd and Churchill 2001).

The similarities, among other things, include aggressive programs of acquisition and dissemination of primary geoscience data; the move to Internet-enabled product distribution; full integration of all of the geoscience disciplines, land access and land claims issues; and the establishment of standards to ensure consistency across all projects.

The types of differences are diverse, ranging from geology, climate and field logistics to client expectations regarding the publication of data. The needs and priorities of the respective mineral industry clients differ particularly with respect to demand for digital versus paper products. Product releases in Ontario must provide for both the digital client and the analogue, or map-based client. In addition, publication releases must be carefully orchestrated to ensure that all clients have simultaneous access. Because the New South Wales clientele is more homogeneously digital, data releases are primarily digital with map products available on demand. The ability to publish digital-only allows the GSNSW to provide data virtually real-time throughout the life of a project.

The OGS geologic programs are administered by both the Sedimentary Geoscience Section and the Precambrian Geoscience Section. This separation is needed because of the unique scientific and operational challenges that each discipline presents for efficient and effective program delivery. Exchange of information between administrative units is critical. For example, the interpretation of geophysical information requires an understanding of the characteristics and distribution of overburden in order to more effectively interpret the bedrock. Ontario may enjoy the benefits that glacial scouring provides, but widespread coverage by transported material represents a big challenge for geological interpretations and mineral exploration. In that much of the surficial material in New South Wales is not transported and the regolith on surface reflects the underlying bedrock, the surficial and bedrock geology are not studied and mapped by separate teams.

The climate, topology, and infrastructure in Ontario present a logistical challenge that effectively limits the geologic field season to 6 months of the year. Furthermore, the costs of mobilization to and from the more remote projects limits the field work to a single excursion each year. In the GSNSW, mapping can be carried out virtually year round and access and infrastructure support are less onerous.

The OGS's ongoing consultation with its advisory board provides a strategic framework for program planning which can respond quickly to the ever-changing needs of the mineral exploration community. The OGS is currently operating under a balanced program that targets both high-risk, unexplored areas and established mining camps.

The geophysical program at the OGS-PGS fulfills 2 distinct roles: geophysical expertise to the teams carrying out the on-going bedrock mapping program; and management of geophysical data acquisition and distribution through extraordinary funding such as OTH. Because OTH originated as a two-year programme, the OGS elected to contract out the required geophysical expertise. In contrast, the longer terms of the GSNSW's six-year Discovery 2000 program and seven-year Exploration NSW: Mining Beyond 2000 program allow for the hiring of geophysical expertise.

The geophysical program within the GSNSW provides an excellent model of integration. The challenge for the OGS-PGS will be in adapting the best practices of the GSNSW to the Ontario environment.

OTHER ACTIVITIES

Much of the consultation process with First Nation communities located within the current airborne geophysical survey areas was carried out under the OTH geophysical program. Nevertheless, the OGS provided support for the open houses at the Dryden airport for the Eagle Lake and Wabigoon First Nation communities and, in Fort Hope, for the Eabametoong First Nation community. OGS personnel presented an overview of geology, geophysics and mineral exploration and communicated the many ways in which minerals impact our lives.

Survey design and planning support has been provided for several projects in co-operation with Natural Resources Canada, the mineral exploration industry, First Nations communities, Industry Canada, and Indian and Northern Affairs Canada.

Support for the Provincially Significant Mineral Potential (Berger and Debicki 2000) project involved the identification, assessment, and compilation of available geophysical data and provision of maps and digital imagery.

Ongoing collaboration with other business units within the Ministry of Northern Development and Mines include technical exchange with, and contribution to, the Geoscience Assessment Office, Resident Geologist Program, Mines Group, Information and Marketing Services Section and the OTH initiative.

The PGS geophysicist supported and enhanced the compilation of the available geophysical data and metadata for the geophysical atlas being generated through funding from the OTH initiative (Reford et al., this volume). PGS involvement included the identification and compilation of seismic, magnetotelluric, and rock property data sets that will constitute part of the information available over the Internet.

If you have any questions, comments or suggestions regarding the role of geophysics in the PGS, please contact the author:

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25. Sudbury Targeted Geoscience Initiative (TGI): Role of Volatiles, Structure and Host Rocks in the Evolution of Sudbury Ores

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INTRODUCTION

The Sudbury Targeted Geoscience Initiative (TGI) is a three-year program (2000 to 2003) designed to gain a better understanding of the setting and processes involved in creating the world's largest nickel-copper-platinum group elements (PGE) deposits of the Sudbury Structure. The federal initiative is a collaborative project between the Geological Survey of Canada, the Ontario Geological Survey, the mining industry and several universities.

The Sudbury Structure (1.85 Ga) is host to more than 60 nickel, copper and PGE producing deposits, past producers and prospects, which are divided into 4 deposit types 1) "contact" magmatic nickel-copper deposits and poorly understood PGE-rich ores in 2) "offset dikes", 3) "footwall" dominantly in veins, and 4) tectonically modified deposit types (Morrison, Jago and White 1994). The diverse deposit styles associated with the Sudbury Igneous Complex (SIC) (1.85 Ga) span a protracted period of ore generation in different ore-forming environments, and many deposits were affected by subsequent deformation.

PROJECT OVERVIEW

This project involves integrated structural, alteration and sulphide mineralogical and chemical studies to determine the mode of evolutionary controls on the ore deposits. Geoscience mapping projects targeted 1) structural controls on the footwall nickel-copper-PGE deposits in the metal-rich Levack embayment, 2) volatile and alteration studies of the igneous component of the Sudbury Structure, and 3) structural studies in the South Range (Figure 25.1). These studies contribute to a better understanding of the role of structures in the formation and modification of the ore deposits, identify the controls on volatile fluid flow, and determine the effects from the overprinting Penokean Orogeny.

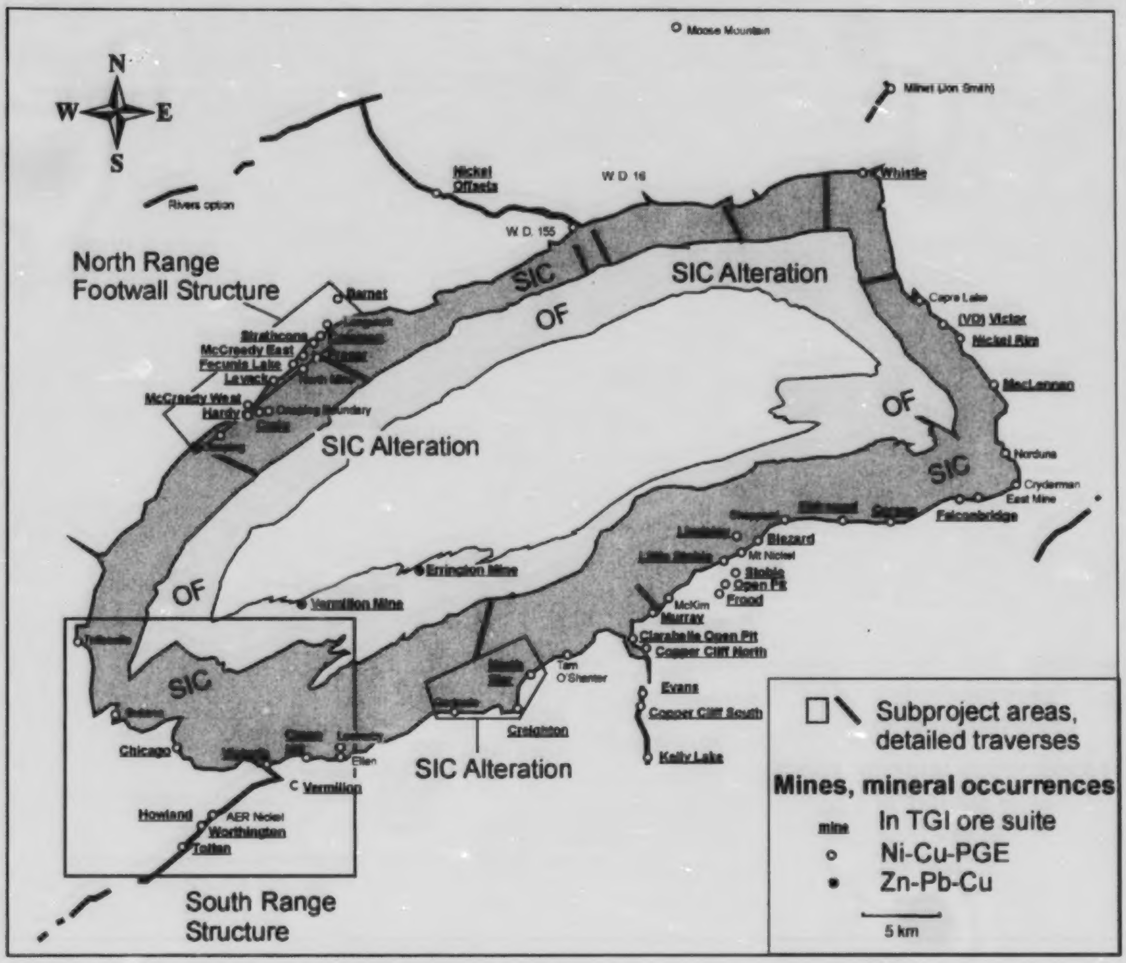
N
W
E
S
Moose Mountain
Milnet (Jon Smith)
Rivers option
Nickel Offsets
W.D. 16
W.D. 155
Whistle
North Range Footwall Structure
SIC
SIC Alteration
OF
Barnet
Strathcona
McCreedy East
Fecunis Lake
Levack
North Mine
McCreedy West
Hardy
Onaping Boundary
SIC Alteration
Capre Lake
(VD) Victor
Nickel Rim
MacLennan
OF
Nordune
SIC
Crydermann
East Mine
Falconbridge
Blezard
Mt Nickel
Stobie
Open Pit
Frood
McKim
Murray
Errington Mine
Vermilion Mine
OF
SIC
Clarabelle Open Pit
Copper Cliff North
Tam O'Shanter
Evans
Copper Cliff South
Kelly Lake
Creighton
Chicago
Ellen
SIC Alteration
C Vermilion
Howland
AER Nickel
Worthington
Totten
South Range Structure
Subproject areas, detailed traverses
Mines, mineral occurrences
mine In TGI ore suite
○ Ni-Cu-PGE
● Zn-Pb-Cu
5 km

Figure 25.1. Location map of TGI subprojects in the Sudbury Structure. Abbreviations: SIC, Sudbury Igneous Complex; OF, Onaping Formation. North Range Footwall Structure and South Range Structure refer to TGI structural studies.

SUBPROJECTS

Alteration Study of Sudbury Igneous Complex

(D.E. Ames, A.G. Galley and I.M. Kjarsgaard)

Hydrothermal-magmatic processes and mineral assemblages are well documented both in the crater-fill sequence situated above the SIC (Ames, Watkinson and Parrish 1998; Ames 1999) and in the footwall environment below the SIC (Farrow and Watkinson 1997, 1999; Watkinson 1999; Molnar, Watkinson and Everest 1999; Molnar, Watkinson and Jones, in press), however, alteration within the SIC is poorly understood (Figure 25.2). Significantly, chlorine- and fluorine-rich minerals and fluids are associated with the copper-PGE mineralization in the footwall (Farrow and Watkinson 1992, 1997; Jago, Morrison and Little 1994) with deep formational brines (Farrow, Watkinson and Jones 1994) as the inferred source of

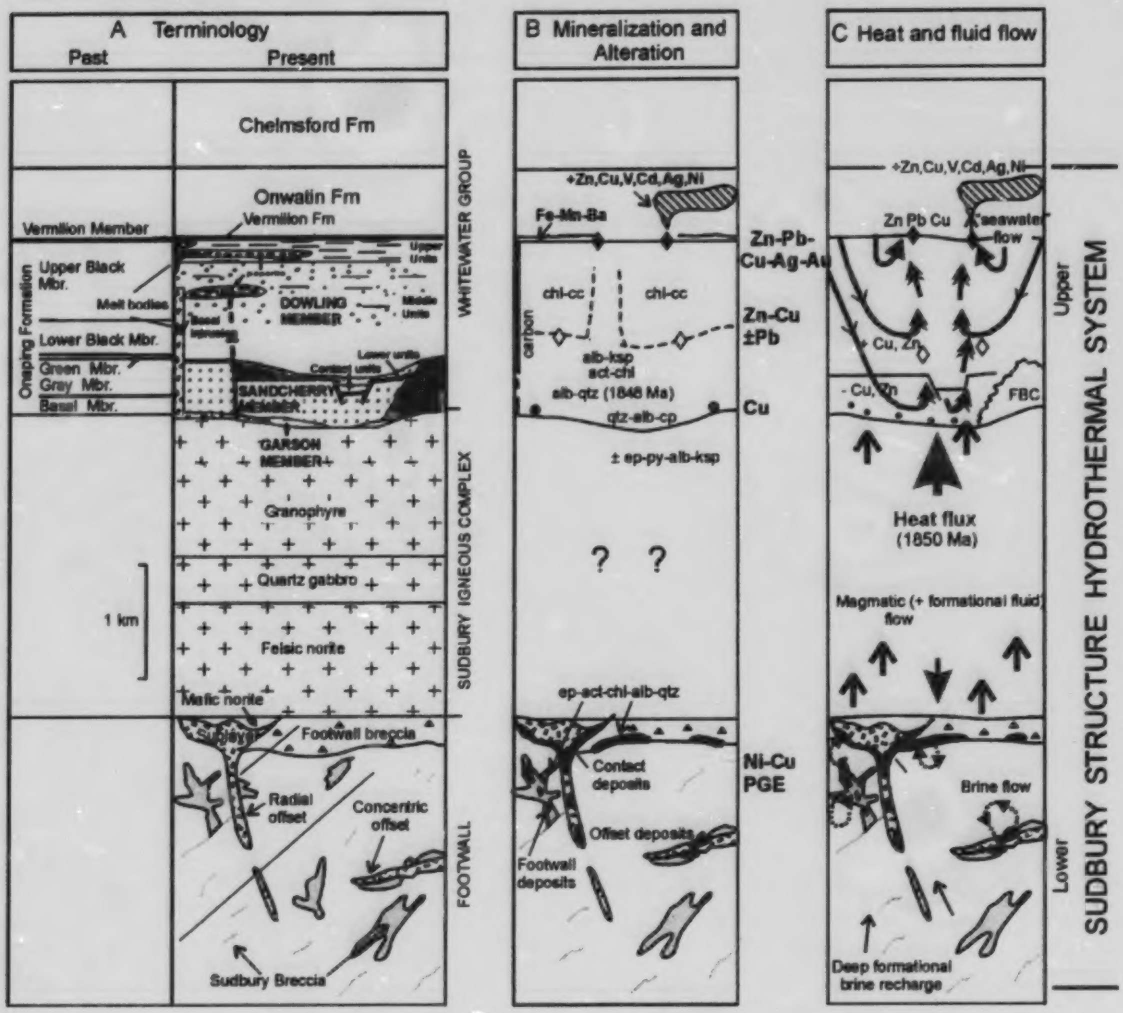
A Terminology
Past
Present
Chelmsford Fm
Onwatin Fm
Vermilion Fm
Vermilion Member
Onaping Formation
Upper Black Mbr.
Melt bodies
Lower Black Mbr.
Green Mbr.
Gray Mbr.
Basal Mbr.
Upper Units
DOWLING MEMBER
Middle Units
Basal intrusion
Lower units
Contact units
SANDCHERRY MEMBER
GARSON MEMBER
Granophyre
Quartz gabbro
Felsic norite
Mafic norite
1 km
Sublayer
Footwall breccia
Radial offset
Concentric offset
Sudbury Breccia
WHITEWATER GROUP
SUDBURY IGNEOUS COMPLEX
FOOTWALL
B Mineralization and Alteration
+Zn,Cu,V,Cd,Ag,Ni
Fe-Mn-Ba
chl-cc
chl-cc
carbon
alb-ksp
act-chl
alb-qtz (1848 Ma)
qtz-alb-cp
± ep-py-alb-ksp
? ?
ep-act-chl-alb-qtz
Contact deposits
Offset deposits
Footwall deposits
Zn-Pb-Cu-Ag-Au
Zn-Cu ±Pb
Cu
Ni-Cu PGE
C Heat and fluid flow
+Zn,Cu,V,Cd,Ag,Ni
Zn Pb Cu
seawater flow
Cu, Zn
- Cu, Zn
FBC
Heat flux (1850 Ma)
Magmatic (+ formational fluid) flow
Brine flow
Deep formational brine recharge
Upper
Lower
SUDBURY STRUCTURE HYDROTHERMAL SYSTEM

Figure 25.2. Schematic sections through the Sudbury Structure showing A) terminology, B) mineralization and hydrothermal alteration, and C) fluid flow and heat flow from the SIC.

A) The terminology in the Onaping Formation is changed as a carbon boundary that delimits obsolete "Gray and Black Members" irregularly transects well-mapped stratigraphic contacts (Gibbins 1994; Ames et al. 1997; Ames, Watkinson and Parrish 1998; Ames 1999). *Modified from* Grieve, Stoffler and Deutsch (1991).

B) The distribution of hydrothermal alteration and the different ore types is shown, however, an alteration study of the SIC does not exist. Regional hydrothermal alteration zones in the crater-fill extend around the circumference of the basin and are related to emplacement of the SIC (Ames, Watkinson and Parrish 1998), data for alteration studies *from* Ames (1999), Farrow and Watkinson (1999), Farrow, Watkinson and Jones (1994).

C) Section showing heat and fluid flow fueled by the SIC (1850 Ma). Fluids include seawater, evolved seawater and "magmatic" fluid flow through the crater-fill; magmatic and formational fluid flow in the SIC and in the footwall; and deep formational brine flow of groundwaters. *Modified from* Farrow and Watkinson (1999) and Ames (1999).

chlorine-rich fluids. Scapolite was identified petrographically in the 1960s in the norite phase of the SIC in the South Range (E. Pattison, INCO Ltd., personal communication, 1999), however, its distribution and composition was poorly understood. Establishing the timing, origin and composition of scapolite in the SIC is significant as it could relate to a sulphate, carbonate or halide species and may be metamorphic or hydrothermal in origin. Multiple hydrothermal processes have been defined in the footwall of the SIC ranging from events predating 1.85 Ga to neotectonic hydrothermal remobilization (Molnar, Watkinson and Everest 1999; Molnar, Watkinson and Jones, in press; Marshall et al. 1999).

In 2001, regional mapping of the SIC was pursued to describe alteration mineral assemblages and their modes of occurrence and spatial distribution in order to determine their role in the ore formation or modification processes. Regional bedrock mapping in 2001 consisted of a focussed study of the nature and distribution of alteration in the norite above the Creighton super-embayment and detailed traverses across the SIC in both the North and South ranges (*see* Figure 25.1).

CREIGHTON–GERTRUDE–NORTH STAR STUDY

Detailed mapping and sampling (>160 samples) of the norite above the Creighton–Gertrude–North Star deposits was conducted to determine the distribution of halogens and alteration assemblages in and around an ore-bearing embayment structure. Preliminary petrographic and field ultraviolet fluorescence observations indicate that scapolite occurs as pervasive replacement, veinlets, and in rare 2 cm vug infillings dominantly within the upper half of the norite in the Creighton area. Mineral chemistry analyses of 29 grains reveal a mid-range meionite-marialite species with 50.2 to 63.5 100*Na(Na+K+Ca), 6.0 to 8.0 weight % Na and 2.0 to 2.7 weight % Cl. Determining the timing, the mode of occurrence and the associated mineral assemblages with the chlorine-rich scapolite is important in understanding the halogen involvement in the volatile history of the SIC and its relevance to the nickel-copper-PGE deposits.

Follow-up studies shall include petrographic, mineral chemical and geochemical studies to characterize the alteration types of the SIC and to determine their paragenesis and magmatic, hydrothermal or metamorphic origins.

GRANOPHYRE STUDY

The purpose of this study is to determine the presence and nature of textures and structures that could have formed during the crystallization of the granophyre phase of the SIC due to volatile fluid generation and migration. The interest in the role of volatile exsolution within the granophyre is two fold: 1) to determine whether degassing of the granophyre is responsible for some of the alteration features present within the overlying Onaping Formation clastic strata (Ames 1999); and 2) to determine whether volatile degassing was focussed along syn-crystallization structures whose locations were influenced by the presence of growth faults in the Onaping Formation (Ames 1999) and/or nickel-copper-PGE-rich footwall structures. If the latter case exists, the pattern and attendant alteration associated with zones of volatile fluid migration may become an important vector in identifying the nature and extent of unexplored zones with high mineral potential.

The 2001 field season involved the completion of a number of detailed traverses across the SIC in both the North and South ranges of the Sudbury Structure. In the North Range, road traverses were completed through the Onaping Falls section along Highway 144, north of Capreol, and up to Ella Lake (*see* Figure 25.1). Lakeshore traverses included the east side of Joe Lake; both the east and west shores of Nelson Lake; a traverse between Falconbridge Ltd's. Fraser Mine; and the Moose Lake tailings facility. One traverse was completed through the South Range granophyre along Highway 144 north of INCO Ltd's. Gertrude and Creighton mines.

Field work included mapping of alteration and careful, systematic sampling of outcrop areas to assist in determining if textural variations indicated mineral and chemical alteration. Detailed structural measurements included orientations of linear features as defined by veins, miarolitic cavity trains and textural variation. This included disequilibrium textures displayed by dendritic amphiboles and discrete pegmatite-aplite growth. An important objective of the structural measurements was to devise a method to quantify the variations in miarolitic-cavity distribution, shape and mineralogy, in order to recognize statistical variance on both the outcrop and regional scale.

Empirical results to date suggest that the intensity and nature of structures and alteration, apparently associated with volatile exsolution and migration, vary greatly from one section to another. It has yet to be determined whether these variations are systematic or predictable. The remainder of the 2001 to 2002 fiscal year will be spent preparing samples for petrographic, mineralogical and geochemical analysis, and comparing the resulting data with the geological information gathered in the field.

Structural Geology of North Range Footwall Rocks of the Sudbury Igneous Complex

(D. Legault, B. LaFrance, D.E. Ames)

Copper- and PGE-rich veins in footwall deposits of the North Range occupy impact-related fractures cutting across the Sudbury Breccia. The main objective of the subproject is to define the geometry and spatial distribution of the Sudbury Breccia and impact-related fractures in the North Range. Understanding the structural controls on the distribution of the Sudbury Breccia and fractures may provide new insights on the formation of the poorly understood copper- and PGE-rich vein systems.

The project began this summer with 1:10 000 scale mapping of the Levack embayment (*see* Figure 25.1) as part of a MSc thesis at Laurentian University (by D. Legault). Different types of breccias have been identified during the mapping: 1) an older Archean granitic breccia, 2) the Sudbury Breccia, and 3) a later granite breccia (Footwall Breccia; Morrison, Jago and White 1994). The Sudbury Breccia comprises fragments of the Levack Gneiss within a matrix that varies in grain size from aphanitic to coarse grained and in texture from massive to flow banded. A few fragments of the Levack Gneiss are cut by narrow cataclastic shears that do not extend into the matrix of the breccia. This suggests that the formation of the Sudbury Breccia began with the propagation of narrow cataclastic shears. Older Archean structures may have played a significant role in the development of the breccia because several irregular bodies of Sudbury Breccia occupy the hinge of an Archean antiform. The granite breccia contains fragments of the Levack Gneiss as well as rare fragments of the Sudbury Breccia within a coarse granitic matrix. Degassing vesicles and "sweats" of epidote in the matrix of the granite breccia may suggest that the breccia crystallized at low crustal depth after the meteoritic impact.

Post-impact sulphide minerals (chalcopyrite, pyrrhotite and pyrite) and epidote-calcite-actinolite veins cut across the Sudbury Breccia and Levack Gneiss. One set of sulphide veins is shallow dipping and west striking, a second set is east striking and subvertical. The epidote-calcite-actinolite veins could not be divided into orientation sets. Their seemingly random orientation could result from grouping together different generations of veins which formed at different times either prior to, during or after 1.85 Ga. Subgrouping of the veins in terms of their mineral assemblages and mineral chemistry will be attempted this winter to determine any possible chemical and geometrical relationships with the mineralization; and their relationship with alteration types mapped in the alteration study of the SIC (*see* "Alteration Study of Sudbury Igneous Complex").

The Sudbury Breccia will be studied under the optical and scanning electron microscopes to research the deformation processes involved in the formation of the breccia. Mapping of the vein systems, the Sudbury Breccia, and Archean structures in the Levack embayment will be completed in the summer of 2002.

Structural Analysis of the Western Sudbury Basin

(A. Dubois, K. Benn, J.R. Parker)

An investigation of the lithological and, especially, structural controls on mineralization in the SIC and in its immediate footwall was initiated in 2001 (Dubois and Benn, this volume). The two-year project, supported under an Ontario Geological Survey–University of Ottawa Collaborative Project Agreeement, will involve extensive mapping in contiguous parts of Trill, Drury, Fairbank and Denison townships in the southwest part of the Sudbury Igneous Complex (*see* Figure 25.1). Mapping emphasizes the identification, description and classification of structures related to deformation events, which occurred before, during and after the formation of the SIC (*see* Figure 25.1).

In contrast to the North Range, deformation, which occurred after formation of the SIC, is pronounced in the South Range and in the study area. The deformation involved northwest to southeast bulk regional shortening and large-scale oblique northwest-vergent thrusting on ductile shear zones. The regional shortening, which occurred after the formation of the SIC, may have reactivated some earlier structures and has certainly modified the distribution of mineralized rocks. Structures related to the deformation event include ductile shear zones at various scales, brittle-ductile shearing and extensive normal faulting, possibly related to late stage relaxation of tectonic stresses. The structures may have provided conduits for migration of late mineralizing fluids.

Available geophysical and diamond-drill core data will be incorporated along with the data gathered during mapping in order to constrain the three-dimensional geometry of the lithological units and of the structural geology. This subproject complements the other Sudbury TGI subprojects in identifying the effects of regional deformation, and the resulting structures, on the development and modification of ore deposits.

Trace Element and Trace Mineral Study of Nickel-Copper-Platinum Group Element (PGE) Ores, Sudbury

(D.E. Ames, C.E.G. Farrow, I.M. Kjarsgaard, E. Pattison, I.R. Jonasson, R.A. Zierenberg)

It is widely known that platinum group minerals (PGMs) in nickel-copper-PGE deposits commonly contain the key element(s) S, Se, Te, As, Sb, Bi, Sn, Pb and Hg (Cabri 1981). A number of trace element studies have emphasized the bulk precious metal content of world-class nickel-copper-PGE ore as at Sudbury and Noril'sk (Naldrett et al. 1982, 1994, 1999; Keays and Crocket 1970; Distler 1994). Little attention has been paid to trace elements that constitute platinum group minerals and accessory minerals to assess their relevance to issues of genesis, metallurgy or exploitation of resources. Indeed, there is little geochemical data on the trace element signatures of nickel-copper-PGE sulphide ore (Jonasson, Eckstrand and Watkinson 1987) in marked contrast to that known of other deposit types.

The aim of the sulphide study of the Sudbury Structure deposits and host rocks (Table 25.1; *see* Figure 25.1) is to determine the trace element characteristics of the ores in diverse deposit environments; to identify trace element trends and associations related to mineralogy; to identify the contributions of

Table 25.1. List of mines and footwall rocks in the Sudbury Targeted Geoscience Initiative (TGI) ore and host rock collection.

Ni-Cu-PGE mines	Zn-Cu-Pb	Country rock
Whistle	Errington	**Proterozoic**
Victor	Vermilion	**Huronian Supergroup**
Victor Deep	LW	McKim Formation
East Rim Nickel mine	Tourgny	Stobie Formation
MacLennan	Irwin	Mississagi Formation
Craig	Limerick	Elsie Mtn. Formation
Hardy	Ryan	
McCreedy West	Simmons	**Felsic intrusive rocks**
Fecunis	Morley	Creighton granite
Levack	Nelson Lk	
McCreedy East		**Mafic intrusive rocks**
Fraser		Nipissing diabase
Strathcona Deep		Curtin Twp.
Strathcona		Owen property
Coleman		Janes Twp.
Barnet		Rastall–Alenan
Nickel Offset		Innes
Chicago		LaSalle
Victoria		Dennison Twp.
Crean Hill		
Vermilion Cu-Ni mine		East Bull Lake
Howland		Freewest PGE zone
Worthington		
Totten		Shakespeare–Dunlop
Creighton		
Creighton Deeps		River Valley Complex
North Star		Tom Rose – South zone
Clarabelle pit		
Copper Cliff N		
Evans		
Copper Cliff S		
Kelly Lake		**Archean**
Murray		Levack Gneiss Complex
Frood		Stone quarry
Frood-Stobie		Hwy 144
Little Stobie		Windy Lake-BIF
Lindsley		Barnett
Blezard		
Kirkwood		
Garson		
Falconbridge		

elements from magmatic and crustal sources; and to identify the source(s) of sulphur to elucidate the complex processes involved in Sudbury ore generation. The Sudbury TGI ore and host rock collection includes well-located ore samples from past-producing mines; producing mines; new discoveries and subeconomic deposits from a variety of sources, including the National Research Collection of Minerals and Ores (samples collected since 1887); universities; mining companies; the Ontario Geological Survey; and original field work (*see* Table 25.1).

Mineralogy, paragenetic sequences, mineral chemistry and geochemistry (including S isotopes, F, Cl, Se, Bi, Te, Hg, As, Sb, Pt, Pd, Au, Ag) of the Sudbury TGI suite of ore and sulphide samples is in progress (*see* Table 25.1). The sulphide study complements the extensive sampling of the host rocks to the orebodies in the SIC and footwall subprojects of the Sudbury TGI. Database compilation incorporates the new Sudbury TGI information with mineralogical and deposit data from the literature, industry, academia and government sources.

CONCLUSIONS

Mapping will be completed on the 4 field studies in the summer of 2002 and new geochemical, structural and alteration data will be integrated into digital maps. A digital database of the geochemistry, mineralogy and trace mineral characteristics of the greater than 60 ore deposits, the SIC and footwall rocks in Sudbury (generated from this TGI project) and compiled data will provide a new regional context and important reference material for academia, industry and government. The alteration study of the SIC may be significant for other research on the igneous geochemistry of the SIC and interpretations of origin.

These detailed studies target problems related to the controls on and modification of Canada's world-class nickel-copper-PGE ore deposits and generate new geoscience information to be made available as digital map and database products. This project will provide a lithological, alteration and structural framework for mineral exploration and other clients with rapid transfer of knowledge to the Canadian public. Improved deposit models should increase the effectiveness of exploration for deposits nationally and internationally, thereby increasing the competitiveness of Canadian mining companies.

ACKNOWLEDGMENTS

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Geological Survey of Canada contribution 2001089.

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26. Project Unit 01-005. Structural Analysis of the Western Sudbury Basin in Trill, Drury, Fairbank and Denison Townships

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INTRODUCTION

The Sudbury Targeted Geoscience Initiative (TGI) is a three-year program (2000 to 2003) designed to gain a better understanding of the setting and processes involved in creating the world's largest nickel-copper-platinum group elements (PGE) deposits associated with the Sudbury Igneous Complex (SIC). The initiative is a collaborative project between the Geological Survey of Canada, the Ontario Geological Survey, the mining industry and several universities (Ames et al., this volume). An investigation of the lithological and, especially, structural controls on mineralization in the SIC and in its immediate footwall was initiated in 2001. This two-year project, supported under an Ontario Geological Survey–University of Ottawa Collaborative Project Agreement, involves extensive mapping in the southwest part of the SIC. It emphasizes the identification, description and classification of structures related to deformation events, which occurred before, during and after the formation of the SIC.

This report summarizes field observations carried out during the first 3 months of this project.

PREVIOUS STRUCTURAL STUDIES

The SIC is located at the boundary between the Archean Superior Province, to the north, and metamorphosed Proterozoic (Huronian Supergroup) rocks to the south. The Archean rocks consist of granitic plutons, gneissic rocks and greenschist-facies metavolcanic and metasedimentary rocks. The rocks of the Huronian Supergroup consist of metasedimentary and metavolcanic rocks intruded by granitic plutons and anorthositic gabbro. The SIC is a tripartite magmatic assemblage, consisting of i) norite overlying the Footwall Breccia at the bottom of the SIC, ii) gabbro and iii) granophyre. The Onaping Formation, interpreted to be a fall-back breccia resulting from the meteor impact, overlies the granophyre of the SIC. The SIC is interpreted to be the result of a major impact event (Dietz 1964) that took place 1850 million years ago (Krogh, McNutt and Davis 1982), hereafter referred to as the "Sudbury event".

According to Fueten and Redmond (1997), the geological evolution of the Sudbury area involved 4 main events: 1) the Penokean Orogeny (1870 to 1835 Ma) resulting in displacements along south-dipping thrusts and in large-scale regional folding (Zolnai, Price and Helmstaedt 1984); 2) a "passive" event of granitic plutonism (1750 Ma); 3) a second orogenic event (1450 Ma) that involved southeast over northwest ductile shearing and leading to the formation of the South Range shear zone (SRSZ) (Figure 26.1a); and 4) the Grenville Orogeny (1070 to 1000 Ma).

Much of the present study area lies within the SRSZ, as defined by Shanks and Schwerdtner (1991), who were the first to point out the importance of the deformation in the SRSZ and to describe it. The

SRSZ cuts the Onaping Formation and the southern part of the SIC. The SRSZ is 50 km long by 7 km wide; it is bounded to the north by folded rocks of the Whitewater Group, and to the south by virtually undeformed layered rocks of the SIC (Shanks and Schwerdtner 1991). The SRSZ is expressed by a penetrative fabric in foliated and lineated rocks and is characterized by a large net thrust displacement of approximately 8 km that accommodated much of the horizontal bulk shortening (Shanks and Schwerdtner 1991).

PROJECT GOALS

The study area is located approximately 20 km west of Sudbury. It covers roughly 220 km^2 and includes parts of Trill, Drury, Fairbank and Denison townships (Figure 26.1b). The area was selected for mapping and structural analysis because of its poorly understood economic potential, and because it has undergone a large degree of deformation after 1850 Ma that has strongly modified the Sudbury impact structure (Shanks and Schwerdtner 1991). From an economic geology point of view, potential sulphide-bearing units include the sublayer and a quartz-dioritic offset dike (Worthington Offset; *see* Figure 26.1a) of the SIC, as well as possible structural traps within the footwall of the SIC.

This project focusses on the identification and mapping of rock types and structures in the lower part of the SIC and in the footwall country rocks—structures which may be related to deformation before, during and after the "Sudbury event". Particular attention is paid to the identification and the classification of structures that may have exercised controls on the location of sulphide mineralization.

At the end of the project, we should be able to determine which structures accommodated the post-impact shortening of the western part of the SIC leading to apparent thrust imbrication. Products of this project will include structural profiles—and, if possible, three-dimensional models—to show the geometries of rock units and structures in the subsurface; to quantify the degree of shortening in order to better understand the original shape of the basin; and finally to propose a model for the structural evolution and the kinematic history of this part of the SIC. These objectives will be attained by using the data collected during mapping and petrographic study, and by incorporating geological and geophysical data made available by the mining industry.

METHODOLOGY

Topographic elevation in the study area varies between 250 and 400 m above sea level. The vegetation is not as sparse as reported by Card (1965), but numerous areas are not fully covered by vegetation. Outcrops situated on topographic highs (hills, ridges) are mainly granite, gabbro and quartz-rich metasedimentary rocks. Outcrops along the sides of the 2 main north to south roads that transect the study area provide observation points in pelitic metasedimentary rocks that are generally found at lower topographic elevations. Topographic highs and roadside outcrops allow for a regular geographical distribution of observations.

In total, 310 outcrops have been studied. Geological mapping was conducted at approximately one outcrop per 1 km^2, with more detailed mapping concentrated in specific regions. Structural measurements of foliations and lineations, orientations of shear zones, faults and folds are being compiled and digital maps are being prepared. Sampling of oriented hand specimens was performed at regular intervals in order to determine rock types and microstructures. The various styles of sulphide mineralization in the study area are also being documented and studied.

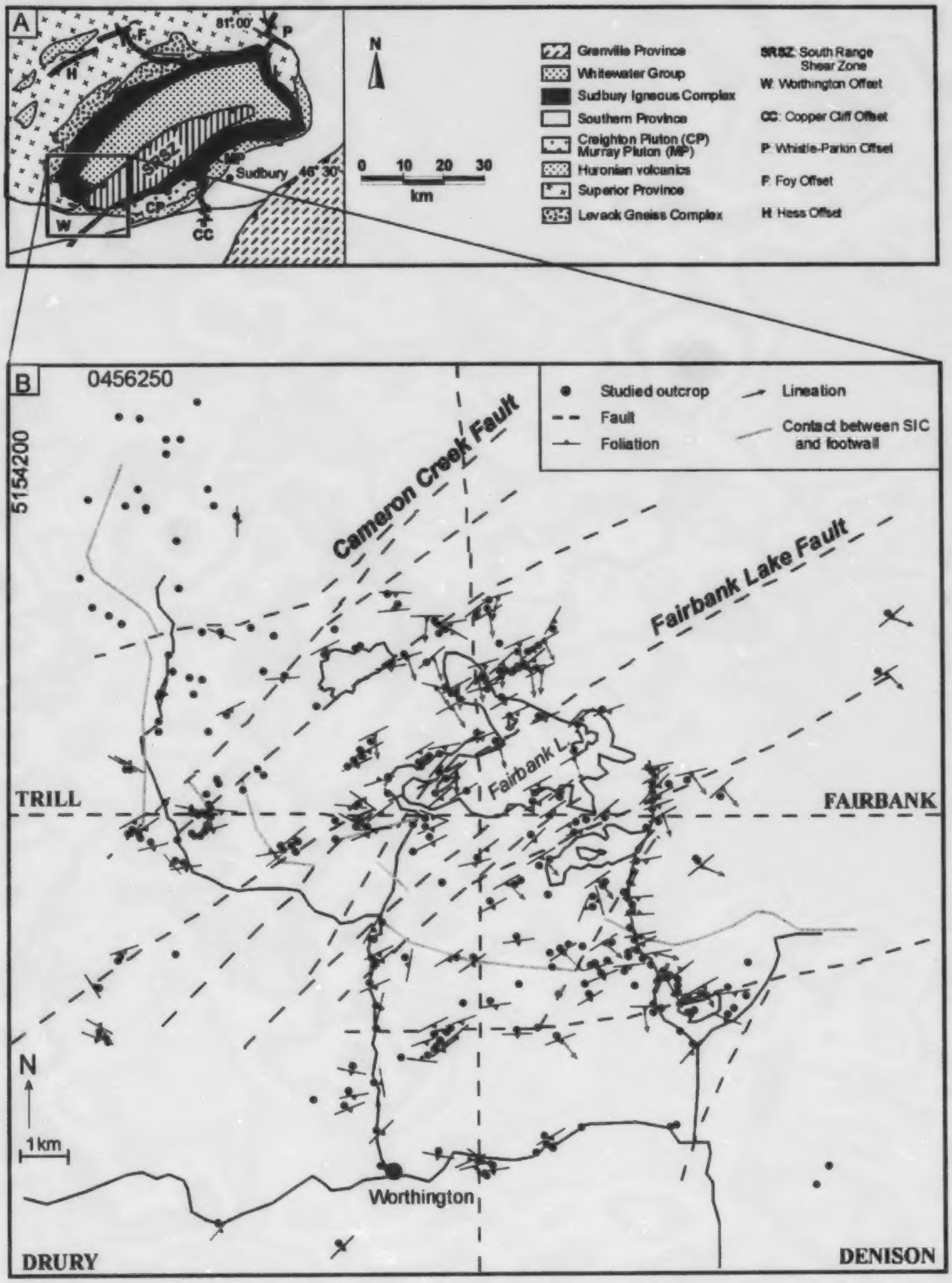
A
81°00'
P
F
H
SRSZ
MP
Sudbury
46°30'
CP
W
CC
N
0 10 20 30
km
Grenville Province
Whitewater Group
Sudbury Igneous Complex
Southern Province
Creighton Pluton (CP)
Murray Pluton (MP)
Huronian volcanics
Superior Province
Levack Gneiss Complex
SRSZ: South Range Shear Zone
W: Worthington Offset
CC: Copper Cliff Offset
P: Whistle-Parkin Offset
F: Foy Offset
H: Hess Offset
B
0456250
5154200
Studied outcrop
Fault
Foliation
Lineation
Contact between SIC and footwall
Cameron Creek Fault
Fairbank Lake Fault
Fairbank L.
TRILL
FAIRBANK
N
1km
Worthington
DRURY
DENISON

Figure 26.1. a) Geological map of the Sudbury basin and location of the area studied. **b)** Ductile deformation elements observed in the study area.

A WORKING MODEL

Data and observations gathered during the first 3 months of this project (some of which are shown in Figure 26.1b) allow us to propose a preliminary working model for the structural evolution of the western Sudbury basin after the "Sudbury event".

Our working model involves thrust imbrication in a transpressive setting. In transpression, strain may be partitioned into 1) predominantly simple shear, concentrated within shear zones and/or faults that are more or less parallel to the bulk regional shear displacements; and 2) predominantly bulk pure shear within intervening rocks. In terranes where horizontal layering is present, the bulk pure shear may be accommodated by *en échelon* folding with axial surfaces striking less than 045° to the regional shear zones and faults. Such a deformation style might be represented by the folds within the layered units that overly the SIC (i.e., the Whitewater Group).

In the study area, after the "Sudbury event", north to south bulk shortening resulted in the development of systems of anastomosing shear zones, within the rocks affected by bulk pure shear. The shear zones affect parts of the SIC, as well as the metamorphic rocks of the Huronian Supergroup within the footwall. The abundant outcrop-scale (and larger scale?) anastomosing conjugate shear zones are steeply dipping and have extension lineations and striations within them that are generally oriented in the dip (subvertical). We interpret that bedding in metamorphosed Huronian Supergroup strata was tilted to steep dips before the deformation event related to the SRSZ. The steep dips of the bedding, possibly inherited from Penokean orogenic deformation before the "Sudbury event", would have precluded the development of regional-scale folds in the Huronian Supergroup rocks during later north to south horizontal shortening. Therefore, the Huronian Supergroup rocks accommodated the regional shortening after the "Sudbury event" by developing shear zones. Interestingly, some sulphide mineralization seems to have a positive spatial relationship with the anastomosing shear zones, suggesting possible remobilization of sulphide mineralization during deformation after the "Sudbury event".

At present, we speculate that bulk simple shear may have been accommodated by large-scale shear zones, such as the Fairbank Lake shear zone, where preliminary kinematic analysis suggests a dextral-oblique sense of shearing.

There is also abundant structural evidence for extensional faulting in the SIC, in the overlying Onaping Formation and in the footwall rocks. Some extensional faulting likely occurred during relaxation of tectonic stress, late in the thrusting history in the basin. At least locally, some sulphide mineralization is associated with normal faults in the lower part of the SIC.

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Sedimentary Geoscience Section

27. Project Units 01-12, 00-36. Aggregate Resources Inventory Projects of the Regional Municipality of York and Huron County

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INTRODUCTION

During the summers of 2000 and 2001 the Sedimentary Geoscience Section (SGS) undertook 2 field investigations of the aggregate resources in Huron County and the Regional Municipality of York (York Region) (see Rowell and Gao 2000). York Region is composed of 9 area municipalities and covers 1756 km^2, stretching from Lake Simcoe in the north to Steeles Avenue in the south (Figure 27.1). The population of the region is estimated as 754 000 (York Region Planning & Development Services Department 2001a, 2001b). Previously published aggregate resource inventories of individual townships have been produced by the Ontario Geological Survey (1980a, 1980b, 1981, 1985, 1988). The township scale aggregate resource inventories in this area, however, need to be updated on a regional level (see Kelly and Rowell 1995). Updating is also required because of the continuing and changing extraction activities and the availability of new geological data and maps (e.g., Sharpe and Barnett 1997; Russell and Dumas 1997; Russell and White 1997; Barnett and Mate 1998; Barnett et al. 1999).

Huron County consists of 16 townships and has an area of 3402 km^2 (Figure 27.2). Agriculture is the dominant industry in the county with 98.5% of its total land classified as capable for agriculture. Among the 16 townships in the county, only one is covered by a published aggregate resources inventory report (Ontario Geological Survey 1986). Currently, the county is undertaking a land use planning review and the aggregate resources in the county need to be defined. At the time of writing, the maps for sand and gravel as well as bedrock resources have been digitized.

The purpose of the aggregate inventories is to delineate, define and evaluate the aggregate resource potential within the study areas and to assess the quality and quantity of the sand and gravel resources. This information can be used for infrastructure development and general construction industries, and land use planning.

YORK REGION

Bedrock Resources

The study area is underlain mostly by the Lindsay, Blue Mountain and the Georgian Bay formations of Middle and Upper Ordovician age (Liberty 1969; Russell and Telford 1983). The Lindsay Formation occurs in the northern part of York Region, including Georgina, East Gwillimbury and King townships. The formation is grey to greenish, fine-grained, argillaceous limestone with occasional shale partings along bedding planes. The formation, often fossiliferous, was observed in abandoned quarries on

Georgina Island. The reported formation thickness is up to 60 m (Liberty 1969). This formation is generally not suitable for high quality aggregate uses because of numerous shale interbeds and partings.

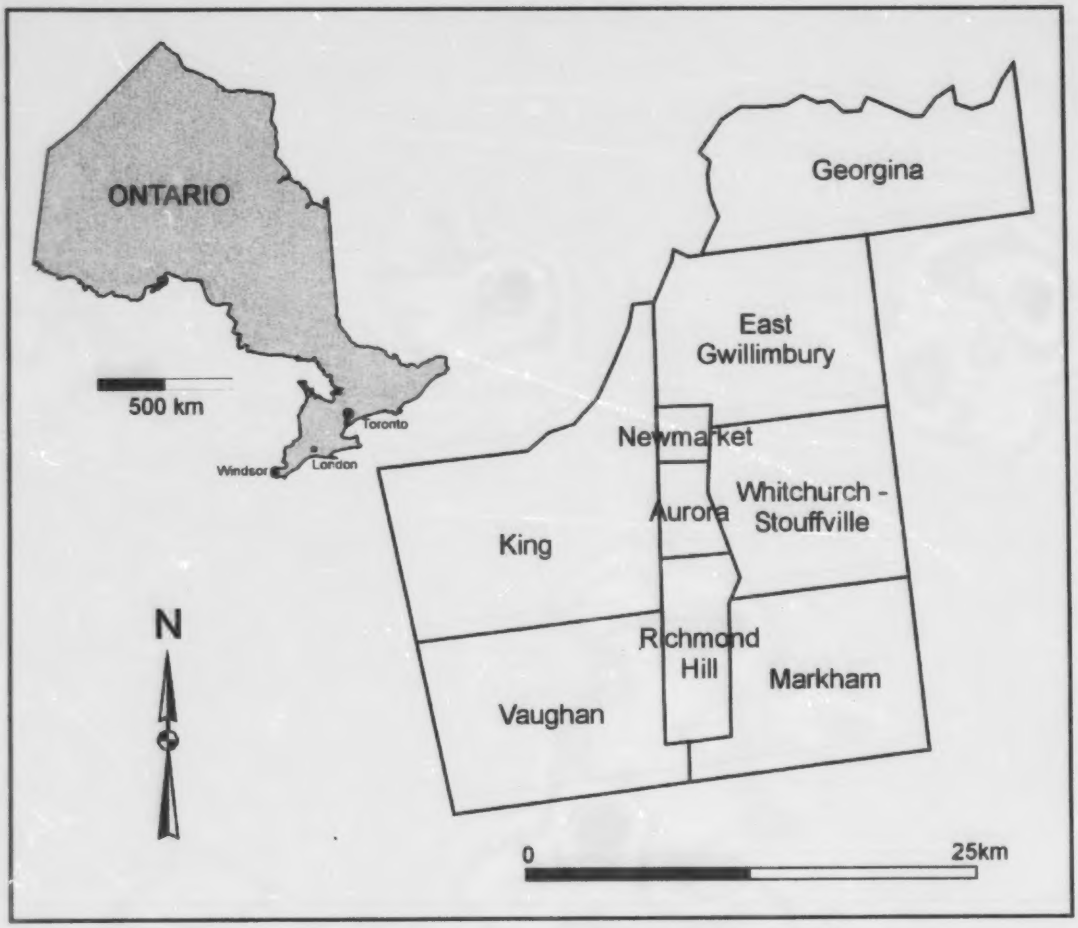
ONTARIO
500 km
Toronto
London
Windsor
N
Georgina
East Gwillimbury
Newmarket
Aurora
Whitchurch - Stouffville
King
Richmond Hill
Markham
Vaughan
0
25km

Figure 27.1. Location of York Region, Ontario.

The Blue Mountain Formation, including the upper and middle parts of the former Whitby Formation, is the predominant bedrock unit in Whitchurch-Stouffville and Markham townships in the central eastern part of York Region (Liberty 1969; Russell and Telford 1983). This bedrock belt narrows to 3 to 4 km wide from Richmond Hill westward to King City and then northwestward where it reaches the boundary of the study area at the Holland River. The formation consists of shale with a brown, blue or grey colour and has a thickness between 40 to 60 m. This bedrock is unsuitable for road-building or construction aggregates.

The Georgian Bay Formation occurs primarily in the western and southwestern parts of York Region and overlies the Blue Mountain Formation. The formation is mainly interbedded limestone and shale and ranges from 90 to 170 m in thickness (Liberty 1969). This unit may have application as a raw material for bricks but is not suitable for road-building or construction aggregates.

Apart from the 3 units discussed above, small occurrences of the Verulam Formation are recorded near the western boundaries of East Gwillimbury and Georgina townships, and on Snake Island in Lake Simcoe. The formation consists of grey limestone with alternating shale and siltstone beds and has a thickness of 30 to 70 m. This unit is of Middle Ordovician age and occurs beneath the Lindsay Formation. Although the rock has been quarried for aggregate in Ramara Township, Simcoe County, it is generally unsuitable for high quality aggregate because of its high shale content.

Throughout the study area the drift thickness is, in general, over 30 m. The excessive thickness of overburden and the lithological unsuitability for use as high quality aggregate suggest that bedrock resources are generally unavailable for aggregate use in York Region under the currently employed technologies.

Surficial Geology and Aggregate Potential

The Oak Ridges Moraine lies in the central part of York Region. Chapman and Putnam (1984) have defined several physiographic regions in the study area. To simplify in this study, the units north of the moraine are collectively called the northern uplands and those to the south, the southern lowland plain.

The northern uplands include the Peterborough drumlin field, Simcoe lowlands and the Schomberg clay plain (Chapman and Putnam 1984). Silty sand diamicton is commonly found in the drumlins. North aligned, flat-floored valleys of 1 to 4 km wide and up to 50 m deep occur in the drumlin field (Barnett et al. 1998). Sand or silty sand is commonly present in the upper part of the valley fill. Shoreline-like small ridges were found at many localities on the slopes of the valleys as well as drumlins. The Simcoe lowlands, which connect to the flat-floored valleys, are low-relief swampy areas around Lake Simcoe and contain clay, silt and sand. South-trending eskers occur in this area. The Schomberg clay plains are located near Schomberg and Newmarket and consist of lacustrine silt and clay. The clay plains are underlain by a drumlinized till plain (Chapman and Putnam 1984).

A deposit of well-sorted sand and gravel with large planar crossbedding was observed at Newmarket. This unit is over 4 m thick and overlain by 2 m of clayey till. Both the sedimentary and morphological features suggest a deltaic origin. Within the region sorted sand and gravel is generally found in the eskers, paleo-shoreline beaches and undifferentiated glaciofluvial sediments (ice-contact stratified deposits). Where suitable conditions exist, extraction has been conducted for years and, as a result, only limited resources are left at surface or near the surface at these sites.

The Oak Ridges Moraine is a regional landmark, running westerly across several townships in York Region. It has a hummocky or hilly landscape and stands above the surrounding lowlands. The moraine is generally composed of sand, gravel, silt and till. Sorted gravel deposits are frequently overlain by thick till deposits. The drift thickness exceeds 150 m at some localities (Barnett et al. 1998). Well to fairly well sorted sand deposits occur commonly in the moraine and often have a glaciofluvial or glaciolacustrine origin. Windblown sand dunes also occur locally (Barnett et al. 1999).

At the village of Holt, sorted gravel deposits occur in south-trending ridges and their extension may be present further to the north beneath the glaciolacustrine sediments. These ridges may indicate an esker, which acted as the feeder system to the Holt Fan defined by Barnett et al. (1998). Thick sand and gravel is found beneath the surface till in a southwest-trending zone from Musselman Lake to Oak Ridges. It is believed that it was deposited in a glaciofluvial or deltaic fan environment (Barnett et al. 1998). The deposit fines to the southwest and becomes sand or pebbly sand at Oak Ridges. Although only 3 pits are currently active among the licenced 13 pits, this area is still of importance for aggregate because of its proximity to Toronto.

The southern lowland plain includes the physiographic units of the south slope and Peel plain (Chapman and Putnam 1984). It has a rolling to flat topography and consists of silty and clayey till deposits with some occurrences of glaciolacustrine silt and clay. The argillaceous nature of the sediments suggests relatively low aggregate potential.

At localities in Vaughan Township the Humber River has incised 20 to 30 m into the plain and revealed buried sand and gravel beneath the till deposits. In general, the till overburden covering the aggregate exceeds 6 to 10 m and extraction often takes place laterally from the river. Extraction used to be frequent in the valley providing material for construction of Highway 400 in the 1950s. The aggregate materials were from either the gravelly alluvial deposits or the buried sand and gravel or both. Sedimentary features suggest a fluvial/glaciofluvial origin for the buried sand and gravel, which may have a wider distribution beyond the valley. The buried deposit is often cemented and frequently contains siltstone, shale or sandstone; these factors may devalue its importance for use in aggregate products.

HURON COUNTY

Bedrock Resources

The majority of Huron County is underlain by Devonian age bedrock of the Dundee Formation and Detroit River Group. Parts of the county are also underlain by the Devonian Bois Blanc Formation and Silurian Salina and Bass Islands formations (Liberty and Bolton 1971; Uyeno et al. 1982; Johnson et al. 1992).

The Salina Formation, the oldest bedrock unit in Huron County, is composed of dolomite, shale, gypsum and salt. Salt is mined at Goderich and Windsor. The Bass Islands Formation consists of medium- to massive-bedded dolomite with shaly partings. It is quarried for crushed stone at several sites on the Niagara Peninsula. Attention must be paid to the detrimental effect of the shaly partings when the material is used for high specification aggregate.

The Bois Blanc Formation consists of cherty limestone with shale partings and minor interbedded dolomite. The formation has been quarried for crushed stone in southwestern Ontario. However, its use for concrete aggregate is limited because of the high chert content.

Two units of the Detroit River Group, namely the Amherstburg and Lucas formations, occur within the county (Uyeno et al. 1982). The Amherstburg Formation has limited occurrence in the northeastern part of Huron County and consists of massive-bedded, laminated dolomite and fine- to coarse-grained limestone. While it may be used in granular base and sub-base course products, this rock is unsuitable for high quality aggregate because of its relatively poor results in soundness, abrasion and absorption tests. The Formosa Reef Limestone Member of this formation occurs near Wingham. This sub-unit consists of high purity limestone and is suitable for lime and cement manufacture.

The Lucas Formation is composed of dolomite with bituminous laminations and minor chert. The formation is borderline to meet the requirements for granular base and sub-base course products. Excessive fines, high absorption and soundness losses in test samples indicate that problems could arise when the rock is used in some aggregate products (Koniuszy and Katona 1981).

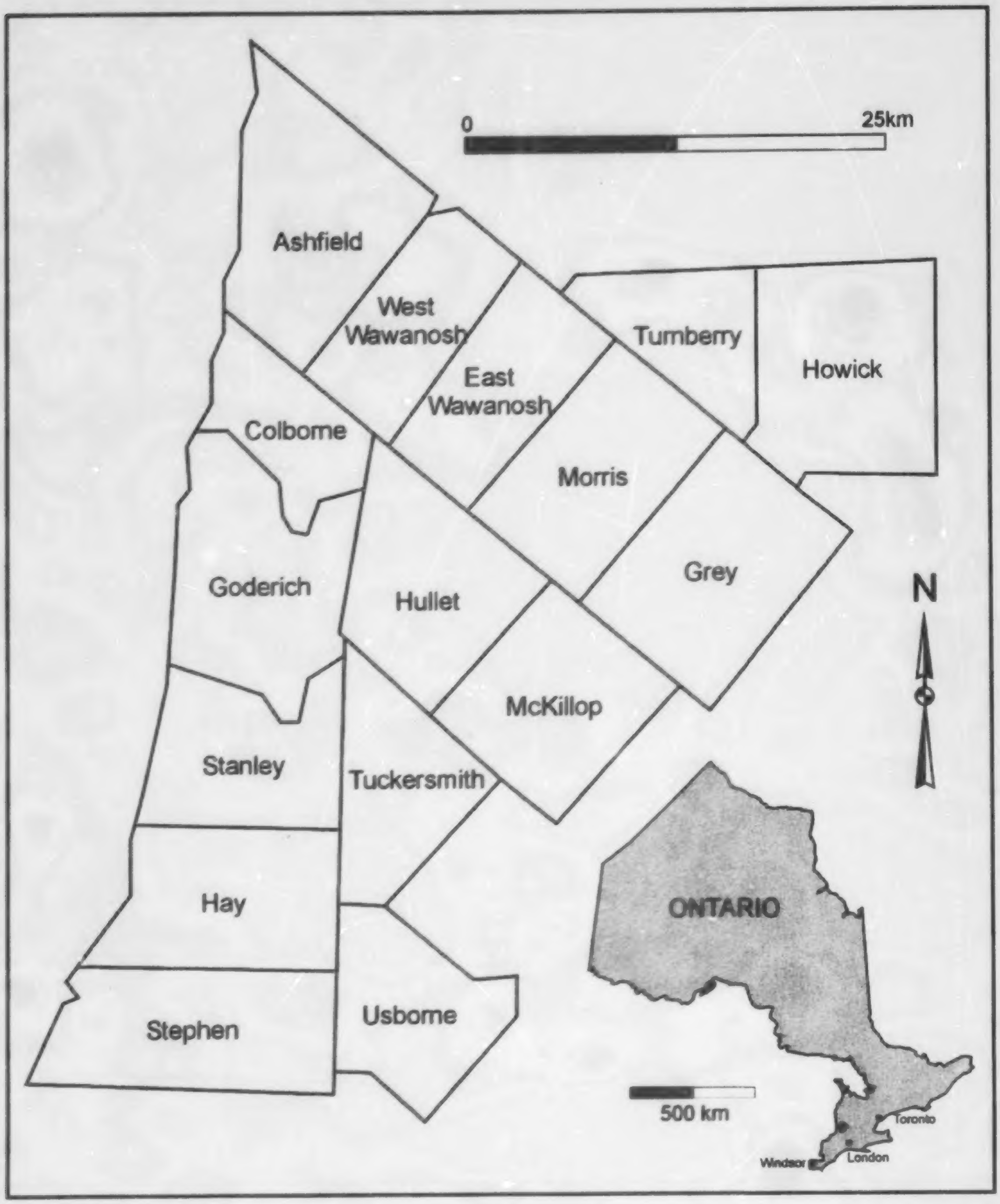
0
25km
Ashfield
West Wawanosh
East Wawanosh
Turnberry
Howick
Colborne
Morris
Goderich
Hullet
Grey
N
McKillop
Stanley
Tuckersmith
Hay
ONTARIO
Stephen
Usborne
500 km
Toronto
Windsor
London

Figure 27.2. Location of Huron County, Ontario.

The Dundee Formation consists of fine- to medium-grained, medium- to thick-bedded dolomitic limestone with shaly partings, chert nodules and lenses of bioclastic layers in some areas. The rock is quarried near Port Dover and on Pelee Island for crushed stone, and used at St. Marys as a raw material for Portland cement. Dundee Formation when used as crushed stone yields poor results in abrasion, soundness and absorption tests, and may cause problems when used in high quality hot mix and concrete applications.

In most of Huron County the bedrock is covered by 10 to 50 m of drift. Only in limited areas, mainly in the valleys of the Maitland River and its branches, is the drift less than 8 m. The thick drift cover suggests that quarrying for bedrock aggregate would be uneconomical in the county using current technologies.

Surficial Geology and Aggregate Potential

Huron County was covered by the advance of 2 ice sheets, namely the Huron and Georgian Bay ice lobes. These ice lobes advanced from the west and north, respectively, during the last glaciation (Karrow 1976; Cooper and Fitzgerald 1977; Cowan 1979; Cowan et al. 1986; Chapman and Putnam 1984). The study area falls into 4 major physiographic regions: the Huron Slope, Horseshoe Moraines, Stratford Till Plain and the Teeswater Drumlin Field (Chapman and Putnam 1984). The first 3 regions are parallel to the Lake Huron shoreline and occur, respectively, in a west to east order. The last region occurs primarily in the northeastern part of the county and has its largest distribution in the townships of Turnberry and Howick.

The Huron Slope, a flat to undulating plain, is composed chiefly of the low-stone content St. Joseph Till (Cooper 1977; Cooper and Fitzgerald 1977). Sorted glaciolacustrine plain or beach sand or sand and gravel occurs as thin beds or low ridges on the plain. The sediment is shallow and generally does not exceed 6 m in thickness. The beach ridges contain sand and gravel, and become sand-rich to the south. In the past, the sorted material was extracted extensively for aggregate in the townships of Goderich, Hay and Stephen. Although a large amount of material has been removed, potential aggregate resources still exist in this type of deposit in the Township of Ashfield.

The Horseshoe Moraines extend in a north-trending belt through Huron County. They consist of several morainic ridges in the south and adjoin the Wawanosh Moraine at Clinton where they continue northward through East and West Wawanosh townships. Large, drainage spillway/meltwater channels occur within the moraines, particularly in Goderich, Colborne, Stanley and Hay townships. Calcareous, clayey silt tills, namely St. Joseph and Rannoch tills, are found in the Wyoming and Wawanosh moraines, respectively. Although present in all the moraines, sorted crevasse or kame sandy or gravelly deposits occur more often in the Wawanosh Moraine. The valley infill in the spillway channels tends to contain coarse-grained aggregate in the north and fine-grained sediments in the south. Hence, sand and gravel is found in Goderich and Colborne townships, and sandy material occurs more frequently in the southern townships of Stanley, Hay and Stephen.

The Stratford Till Plain lies east of the Horseshoe Moraines and adjoins the Teeswater Drumlin Field to the north. The region is a rolling to flat till plain which is divided by 3 major morainic ridges lying sub-parallel to the Lake Huron shoreline. The plain and the moraines consist primarily of Rannoch Till (Karrow 1976; Cooper et al. 1977).

The drumlinized till plain in the northeastern part of Huron County forms the southern half of the Teeswater Drumlin Field. This physiographic region has a larger distribution in Bruce County to the north (Chapman and Putnam 1984). The drumlins are primarily composed of sandy to silty Elma Till which has a moderate to high stone content. There is a large distribution of outwash sand and gravel between Lakelet Lake in the north and the Maitland River in the south. As a result, Howick Township contains some of the richest aggregate deposits in Huron County.

Eskers occur frequently in the Stratford Till Plain, Wawanosh Moraine and the eastern part of the Teeswater Drumlin Field. They generally trend to either the south or the east, reflecting the general flow directions of the Georgian Bay and Huron ice lobes. Numerous eskers with a south or south-southeast alignment are found in East Wawanosh and Morris and in the northeastern part of Grey townships. East trending eskers are seen mostly in the south in the southern parts of East Wawanosh and Morris, and in McKillop and Hullet townships. Large eskers are also seen near the northern boundary of Usborne Township. Because of their importance as aggregate sources, many of the large eskers have been mined intensively, and their surface or near surface resources are nearly depleted, in particular in Grey and Morris townships.

Many small to medium-sized eskers were found, particularly in the forested areas, through aerial photograph interpretation or field investigations. Wherever possible, field visits were made to examine these eskers. In McKillop Township, a buried 5 km long, easterly running esker was detected on the aerial photographs. The subsequent field examination indicated that although difficult to see on the ground, the esker occurs as low sandy or gravelly ridges at certain localities.

Fans or fan deltas deposited in subaqueous or subaerial conditions were identified within the morainic complex in East Wawanosh and Howick townships through field investigations. Some of the fans display kettles (formed in a dead-ice environment) at the fan heads and steep slopes at the edges, suggesting ice-proximal and -walled conditions. These geological entities often stand above the surrounding area and contain relatively consistent, high quality sand and gravel with a thick depth. They are, therefore, important aggregate sources. Detailed studies of these glaciofluvial deposits may be of assistance in searching for new aggregate sources in this area.

In summary, Howick, Turnberry, East Wawanosh, Goderich and Colborne townships in the northern and central western Huron County are rich in sand and gravel resources. The host geological deposits are spillway channels, fans and eskers. The townships south of Goderich, including Stanley, Hay, Stephen and Tuckersmith, generally have low potential for sand and gravel. The remaining townships in the county have moderate aggregate potential with sand and gravel found mostly in eskers, outwash channels and deltas.

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28. Project Unit 01-010. Quaternary Geology Mapping and Overburden Sampling, Longlac Area, Northwestern Ontario

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INTRODUCTION

The Ontario Geological Survey (OGS) has defined several important kimberlite exploration targets over the Kapuskasing Structural Zone (KSZ) through a series of recent overburden mapping and sampling programs (Morris, Crabtree and Averill 1998; Morris, Crabtree, et al. 1998; Morris, Crabtree and Pianosi 1997; Morris et al. 1994 and Stephenson et al. 1999) (Figure 28.1). Kimberlite is the rock type most commonly recognized as the primary host for diamond (Morris and Kaszyki 1997). To define kimberlite exploration targets, overburden samples are processed to isolate kimberlite indicator minerals (KIMs). KIMs are heavy minerals (specific gravity greater than 3.2) that are closely associated with kimberlite. These minerals include Cr-pyrope garnet, chromite, Mg-rich ilmenite, Cr-diopside and forsteritic olivine.

The OGS has also undertaken a number of other overburden sampling programs in northern Ontario to evaluate kimberlite potential (Allan 2001; Ontario Geological Survey 2001a, 2001b, 2001c; Stone 2001 and Tardif 2000). One of the areas included part of the Trans Superior Tectonic Zone (TSTZ), a belt of rock extending from Michigan, across Lake Superior and into Ontario (Figure 28.1). The geology of the TSTZ is favorable to host kimberlite in that it is a fault system that has accommodated the emplacement of mantle material and has mantle-root friendly structures (such as dike swarms) indicating conditions favorable for diamond preservation. This is supported by the presence of kimberlites within Michigan (Cannon and Mudrey 1981) and the presence of ultramafic lamprophyres, which belong to the kimberlite "clan" of rocks (Rock 1990), in Ontario (Sage 1999). Two overburden mapping and sampling programs were completed over the TSTZ along the north shore of Lake Superior during the summers of 1999 and 2000 (Morris 2001; Morris et al. 2000). Again, these programs were successful in identifying excellent kimberlite exploration targets based on the recovery of KIMs and geochemistry of overburden samples.

In addition to KIMs, overburden samples from the 1999 and 2000 field seasons were processed for metamorphic or magmatic massive sulphide indicator minerals (MMSIMs®)[1], gold grains and carbonatite indicator minerals (Morris et al. 2000; Morris et al. in prep). The MMSIMs® are associated with 3 main base metal deposit types: 1) volcanosedimentary massive sulphides in high grade regional metamorphic terrane; 2) skarn and greisen deposits; and 3) magmatic Ni-Cu sulphides (Averill 1999). The composition of gahnite, a rare and important MMSIM® associated with metamorphosed volcanosedimentary massive sulphide deposits, is also used to indicate the presence of rare-element pegmatite (Morris et al. 1997a).

To further evaluate the potential of the TSTZ for kimberlite, base metal, gold and rare element carbonatite mineralization, overburden mapping and sampling was completed farther north along the TSTZ in the area of Longlac during the summer of 2001 (Figure 28.1). The study area is covered by 4,

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[1] MMSIM is a registered trademark of Overburden Drilling Management Limited, Nepean, Ontario

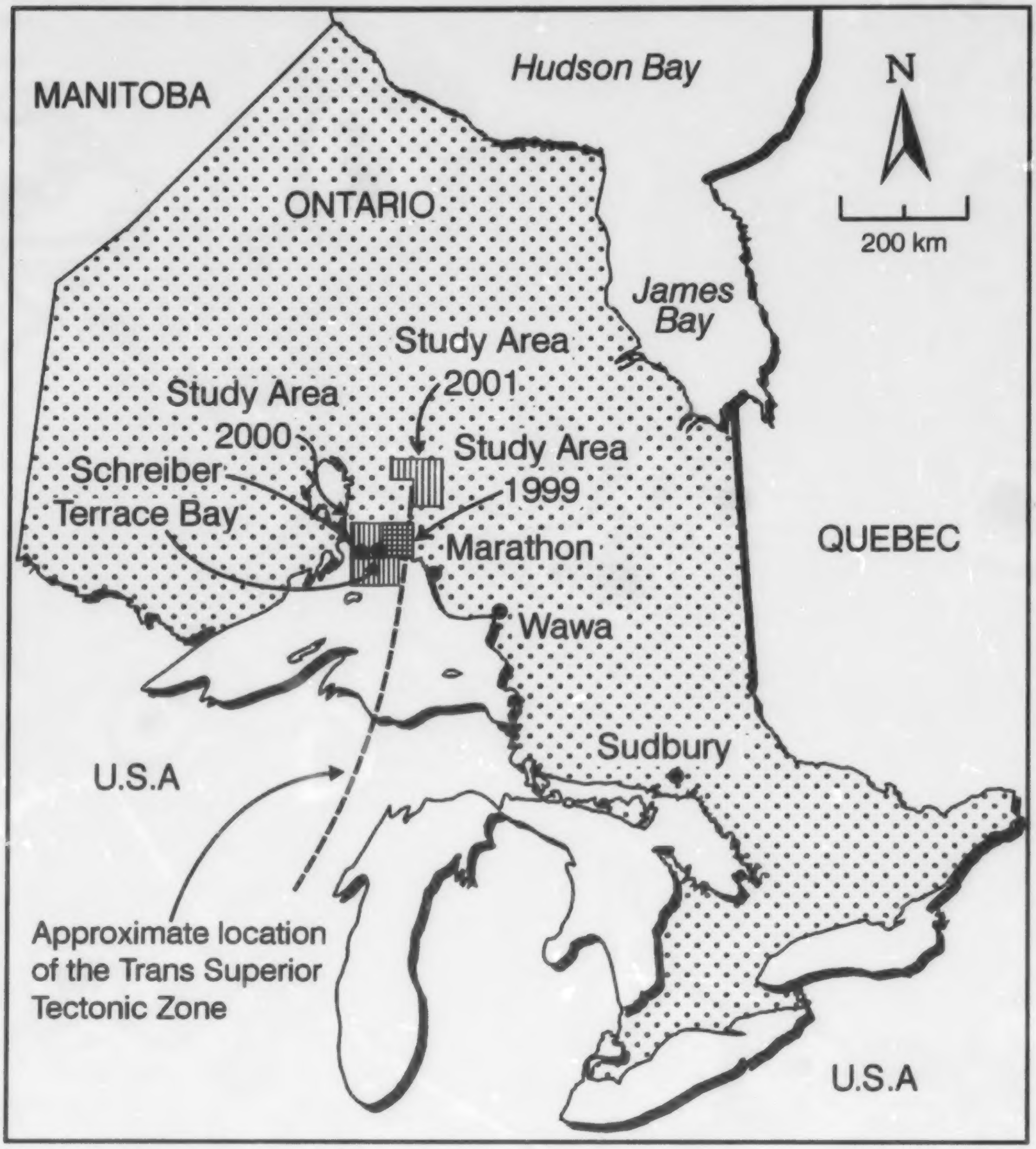
MANITOBA
Hudson Bay
N
200 km
ONTARIO
James Bay
Study Area 2001
Study Area 2000
Study Area 1999
Schreiber
Terrace Bay
Marathon
QUEBEC
Wawa
Sudbury
U.S.A
Approximate location of the Trans Superior Tectonic Zone
U.S.A

Figure 28.1 Location of Trans-Superior Tectonic Zone relative to study area.

1:50 000 scale, National Topographic System maps which include: the north half of the Longlac (42 E/15) sheet, bounded by latitudes 87°00' and 86°30' and longitudes 50°00' and 49°52'; the Castlebar Lake (42 E/16) sheet, bounded by latitudes 86°30' and 86°00' and longitudes 49°45' and 50°00'; the Pagwachuan Lake (42 E/9) sheet, bounded by latitudes 86°30' and 86°00' and longitudes 49°30' and 49°45'; and the north half of the Kagiano Lake (42 E/8) sheet, bounded by latitudes 86°30' and 86°00' longitudes 49°30' and 49°22'. The study area borders the Beardmore-Geraldton area where mapping and sampling was previously completed by Thorleifson and Kristjansson (1993). All overburden samples collected for this study were processed for KIMs, MMSIMs®, gold, carbonatite and Platinum Group Minerals (PGMs).

PHYSIOGRAPHY

The study area straddles the Great Lakes-Hudson Bay drainage divide. Water flows north into James Bay from Burrows, Chipman, Fernow and Pagwachuan lakes through the Kenogami and Fernow rivers. South of the drainage divide, water flows south to Lake Superior through the Pic River.

The study area lies within the Abitibi Uplands subregion of the James Bay physiographic region (Bostock 1976). This region is underlain by crystalline Archean rocks and characterized by a broad rolling surface that rises gently from the Hudson Bay Lowland. Bedrock relief is generally low to moderate, seldom exceeding 60 m (Gartner 1979).

BEDROCK GEOLOGY

The Precambrian geology of the Longlac area has been described and mapped in detail by Kresz and Zayachivsky (1989), Kresz (1989), Innes and Ayres (1971) and Pye et al. (1966). The study area lies within the Wabigoon and Quetico subprovinces of the Superior Province. Within the study area, the eastern Wabigoon is, in part, comprised and associated with the Elmhirst-Castlewood-Klotz greenstone belt that is of Archean age. This belt trends westerly and is characterized as a greenstone pod surrounded by granitoid units. The greenstone belt consists of massive, pillowed, amygdaloidal, variolitic flows of magnesium to iron tholeiites (Mason and White 1986). The granitoid units are transected by the Nipigon Embayment (Blackburn et al. 1991). Rocks belonging to the Elmhirst-Castlewood-Klotz greenstone belt have been intruded by late intrusive (Neo- to Mesoarchean) diorites, granodiorites, quartz-diorites, monzonites, feldspar porphyrys, quartz-porphyrys and pegmatites (Mason and White 1986).

The Quetico subprovince lies to the south of the Wabigoon subprovince. The Quetico consists of Neo-Mesoarchean intrusive and supracrustal rocks composed of a gneissic tonalite suite, muscovite-bearing granites, massive granite to granodiorite and a metasedimentary suite.

Proterozoic diabase dikes intrude all rock types associated with both subprovinces. Metamorphic grade is commonly greenschist but ranges to amphibolite facies (Speed and Craig 1992).

The study area straddles the TSTZ, a prominent structural feature that extends north-northeast from Michigan where several kimberlites occur. This tectonic zone was emplaced between 1.0 to 1.2 Ga (Sage 1991).

QUATERNARY GEOLOGY

It is thought that all glacial landforms and related materials within the study area were deposited during the last Wisconsin Episode glaciation. Previous overburden mapping for the area has been completed at scales of 1:5 000 000 (Prest et al. 1968), 1:1 000 000 (Barnett et al. 1991), 1:506 880 (Zoltai 1965) and 1:100 000 (Gartner 1979). Specific studies or observations on local Quaternary geology features and landforms were reported by Zoltai (1967).

Direction of ice flow within the study area is defined by the orientation of striae, grooves, chattermarks and streamlined bedrock. Most of these features are orientated between 215° to 227°, indicating a regional flow to the southwest. Two different sets of striae were observed at 2 locations in the northern part of the map area. There, the regionally pervasive, southwest orientated striae were abraded into the outcrop surface by flow to the south at 190°.

The till within the study area consists primarily of thin deposits of subglacially derived material with a carbonate-rich matrix. The till's clast lithology is composed of clasts from both local sources and from the Hudson and James Bay lowlands. A less pervasive, locally derived, non-calcareous till is confined primarily to topographically high areas such as bedrock knobs and ridges.

Landforms and materials associated with glacial retreat are found throughout the study area. Ice-contact stratified drift is common. This material is associated with deltaic sequences, recessional moraines, dead-ice topography, eskers and valley fills. Ice-contact stratified drift commonly consists of flow till (with well developed flow structure) and poorly-sorted pebbly sand containing a variety of clast types (from local material to Hudson Bay region derived Paleozoic clasts). The matrix of the ice-contact material reacts strongly with 10% HCl. Several prominent eskers, representing former subglacial conduits that supplied sediment to 3 deltas, occur northwest of Raynar Lake, south of Chipman Lake and southwest of Taffy Lake (NTS sheet 42 E/16). Sections through these eskers reveal well-sorted pebbly sand and coarse gravel.

Glaciofluvial deposits consisting of well-sorted sands to boulders, primarily local provenance, were identified within several narrow valleys. Glaciolacustrine materials were deposited within 2 different environments. First, and primarily within the Pagwachuan Lake map sheet (42 E/9), shallow, short-lived proglacial lakes formed between the receding ice sheet and topographically higher ground. Material associated with these lakes includes fine to medium sand. Second, and primarily within the northern part of the Castlebar Lake map sheet (42 E/16), very fine-grained sand and varved silts and clays were deposited within Glacial Lake Barlow-Ojibway. West of Pagwachuan Lake, water from a proglacial lake spilled over the drainage divide into McKay Lake, then drained south to Lake Superior through the Pic River valley. Post-glacial features such as colluvium, modern shoreline features (such as bars and spits), eolian features (sand dunes), modern alluvium and organic deposits were observed throughout the study area.

PROJECT STATUS

Two hundred and forty-seven modern alluvium samples were collected. The distribution of these samples provides an excellent sample coverage across the study area. These samples have been submitted for heavy mineral analysis to isolate any gold grains, KIMs, MMSIMs®, carbonatite indicator minerals and PGEs grains.

Ninety-two till samples were also collected. Site selection was determined through the use of a hypothetical 5 km^2 grid placed over the study area. As many of these grids as possible were sampled. At each sample site, 250 g samples of each of the humus, "B" and "C" horizons was collected for geochemical analysis. A 10 kg bulk sample of "C" horizon material was also collected for heavy mineral analysis.

Seven additional samples, consisting of 2 modern alluvium, 4 till and an ice-contact stratified-drift (esker) sample, were also collected for heavy mineral and geochemical analysis. These samples were collected approximately 3 km south of Klotz Lake (NTS map sheet 42 F/13) from Golden Tiger's abandoned gold property in order to evaluate gold and base metal potential.

Twenty sand and gravel samples were collected from ice-contact stratified drift, glaciofluvial and coarse-grained glaciolacustrine deposits. These were taken in order to compare the heavy mineral signatures within these materials to the heavy mineral signatures in the modern alluvium samples obtained from streams flowing over these deposits. This data may help in evaluating the contribution of heavy mineral signatures from materials associated with ice sheet retreat to those in modern alluvium.

Clast lithologies were determined for the pebbles contained within bulk samples. This information is essential in determining proximity to source for heavy mineral and geochemical signatures.

One product of this project will be 3, 1:50 000 scale overburden maps. These maps are to be used for a variety of purposes; in addition to assisting drift exploration, they will provide information to aid sand and gravel exploration, the location of environmentally sensitive areas and forestry.

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29. Project Unit 01-011. Regional Modern Alluvium Sampling Survey of the Mattawa – Cobalt Corridor, Northeastern Ontario

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INTRODUCTION

The northern portion of the Mattawa – Cobalt corridor of northeastern Ontario (Figure 29.1), just south of Cobalt, has been a historical area for silver, nickel and cobalt mining operations. A major past producer in both the Cobalt area and south in Silver Center, until the late 1980s, was Agnico Eagle Mines Ltd. In more recent years, the discovery of kimberlites to the north of the survey area in New Liskeard and Kirkland Lake has triggered an increase in diamond exploration across the region (Allan 2001). The western flank of the Lake Temiskaming Structural Zone (LTSZ) lies within the northern part of the study area. A number of faults associated with the LTSZ, including the Net Lake, South Montreal River and McKenzie faults, cross the study area. The northwest trending (325°) LTSZ is believed to be the fault system through which the kimberlites have intruded (Sage 1996). The intersection of orthogonal structures presents potential settings for kimberlite emplacement. Such intersections are represented by the northeast striking Grenville Front Tectonic Zone (Figure 29.1) and the series of northwest trending faults of the LTSZ. Therefore exploration for diamond-bearing kimberlites remains active along the LTSZ (Sage 2000).

The primary objective of the current study is to extend regional information concerning the types and distribution of kimberlite indicator minerals (KIMs) found in modern alluvium in the Mattawa – Cobalt area. Kimberlite is a rock type commonly recognized as the primary host for diamond. The KIM suite of minerals includes pyrope and eclogitic garnets, magnesium ilmenite, chromite, chrome diopside, forsteritic olivine and diamond. The presence of these indicator minerals will be used to determine the prospect and proximity of any potential diamond-bearing kimberlites in the area (Allan 2001). Heavy mineral assemblages are also being examined for gold grains and metamorphosed or magmatic massive sulphide indicator minerals (MMSIMs®[1]).

The Mattawa – Cobalt Corridor study area is represented on 10, 1:50 000 scale National Topographic System (NTS) map sheets. The northern part of the study area is covered by the southeast corner of the Cobalt sheet (31 M/5), the southwest corner of the Ville-Marie sheet (31 M/6), the western edge of the Fabre sheet (31 M/3) and the eastern half of the Temagami sheet (31 M/4). The eastern quarter of the Ingall Lake sheet (31 L/13) and the western half of the Ottertail Creek sheet (31 L/14) cover the central section. The southern part of the study area includes the eastern half of the North Bay sheet (31 L/6), the west half of the Mattawa sheet (31 L/7), the southwest corner of the Lac Beauchene sheet (31 L/10) and the Temsicaming sheet (31 L/11).

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[1] **MMSIM is a registered trademark of Overburden Drilling Management Limited, Nepean, Ontario**

PHYSIOGRAPHY

The northern part of the study area falls within the Cobalt Plain physiographic region and the southern part of the study area falls within the Laurentian Highlands physiographic region (Bostock 1976). The Cobalt Plain, composed of flat lying Precambrian-aged sedimentary bedrock with ridges and hills comprised of diabase intrusions, rises gently from the Hudson Bay Lowland to elevations of 180 m asl (Thurston 1991). Rock escarpments and steep sided gullies are prominent throughout the landscape with swamps and creeks occupying lower lying areas (Allan 2001). The Laurentian Highlands is characterized by rugged terrain that attains elevations of 600 m asl. The landscape is deeply incised by large rivers.

The dominant physiographic feature throughout the entire study area is the Ottawa River system, which occupies a structurally controlled valley (Roed 1979). Major drainage basins represented in the study area include Lake Temiskaming, Trout Lake and the Ottawa River system. Drainage from the lakes and streams in the northern part follow either the gentle northeasterly dipping peneplain to Lake Temiskaming or southwest trending valleys to the Montreal River which flows south-southeast into Lake Temiskaming. In the central region of the study area, drainage occurs in a southerly-southeasterly direction into the Ottawa River. In the southern part of the study area, water bodies drain toward Lake Nipissing, Trout Lake, Mattawa River and easterly into the Ottawa River.

GENERAL GEOLOGY

The intersection of the 3 main provinces of the Canadian Shield – the Superior, the Southern and the Grenville lies within the study area (Figure 29.1). Separating these provinces is the Grenville Front Tectonic Zone (Easton 1991) which divides the area into a northern zone consisting of the Southern and Superior provinces, and a southern zone consisting of the Grenville Province. The main lithologic units in the study area are of Precambrian age and are overlain by a layer of Pleistocene glacial and glaciofluvial deposits and Recent swamp, lake and stream deposits (McIlwaine 1970; Born 1989).

The Southern Province, found in the northern portion of the study area, consists of the Paleoproterozoic Huronian Supergroup (2450 to 2220 Ma) (Bennett et al. 1991). This supergroup is subdivided into 4 stratigraphic groups, the upper most sedimentary cycle being the Cobalt group. The Cobalt group comprises, in ascending order, 4 formations: the Gowganda, Lorrain, Gordon Lake and Bar River formations (Bennett et al. 1991). Of interest to the present study are the Gowganda and Lorrain formations which make up the Cobalt Embayment. The Gowganda Formation consists of distinct, diverse sequences of clast- and matrix-supported conglomerate, pebbly wacke, wacke, siltstone, mudstone and arenite. The Lorrain Formation consists mainly of arkose and quartz arenite and conformably overlies the Gowganda Formation (Bennett et al. 1991). Intruding the Huronian Supergroup are swarms of dikes and sills of the Nipissing Diabase (2219 Ma) consisting of quartz diabase, diorite rock types and related granophyre rock types (Ontario Geological Survey 1991). The Nipissing Diabase is thought to have been one of the important factors associated with the emplacement of the silver-cobalt veins of South Lorrain Township.

The Superior Province is divided into numerous subprovinces including the Abitibi subprovince; the Abitibi subprovince occupies a portion of the northern part of the survey area. The Abitibi subprovince is composed of Archean aged supracrustal to intrusive rocks (Jackson and Fyon 1991). The intrusive rocks consist of a foliated tonalite suite of Neo- to Mesoarchean age (2.5 to 3.4 Ga.). This unit was formerly classified as Algoman and/or Laurentian (Ontario Geological Survey 1991). Supracrustal rocks of the same age include suites of mafic to intermediate metavolcanic rocks composed of minor metasedimentary and intrusive rocks, as well as related migmatites and iron formations. These suites were formerly classified as the Keewatin unit (Ontario Geological Survey 1991).

The Grenville Province occupies the southern part of the study area and is comprised of Mesoproterozoic aged rocks (0.9 to 1.6 Ga.) belonging to the Central Gneissic Belt. The rock suites of the Grenville Province found in the study area include: 1) felsic igneous rocks composed of tonalite, granodiorite, monzonite, granite, syenite and their derived gneisses; 2) anorthosite and alkalic igneous rocks; 3) migmatitic rocks and gneisses of undetermined protolith including layered biotite gneisses and migmatites and locally quartzofeldspathic-, ortho- and paragneisses; 4) mafic rocks including amphibolite, gabbro, diorite and mafic gneisses; and 5) gneisses of metasedimentary origin (Ontario Geological Survey 1991).

QUATERNARY GEOLOGY

During the Wisconsin Episode of the Pleistocene Epoch the study area was occupied by the Labrador Sector of the Laurentide Ice Sheet. Ice accumulation of the Labrador Sector began in the interior uplands of Labrador and Quebec. The ice sheet advanced south and westward across the study area (Barnett 1991). On the basis of glacial striae orientations in the Temiskaming area, it has been proposed that 3 different stages of ice flow direction affected the region. The oldest, a west-southwest flow (230° to 270°) and a younger, south-southwest flow (180° to 220°) were overprinted by the latest regional south-southeast ice flow (130° to 170°) (Veillette 1986).

The surficial deposits observed in the region are thought to have been deposited primarily during the latter part of the Wisconsin Episode. Advance of glacial ice across the area deposited a discontinuous veneer of undifferentiated, sandy to silty till, with a general lack of carbonates, over the bedrock (Gartner 1980). During deglaciation, approximately 10 000 years B.P. at the beginning of the Holocene, glacial Lake Barlow began to form in the valleys of the eastern part of the area as drainage along the valley now occupied by Lake Temiskaming was blocked. By 9 500 years B.P., the ice front had receded well to the north of the study area and Lake Barlow joined with Lake Ojibway to form Lake Barlow-Ojibway. Approximately 8 700 years B.P., the obstructions along the Lake Temiskaming valley were breached and Lake Barlow-Ojibway drained in several stages resulting in modern Lake Temiskaming (Roed 1979). The receding ice front deposited several east-trending moraines across northern Ontario. A major recessional moraine, known as the McConnell Lake Moraine and several associated kame moraines were deposited when the ice front halted at the south end of Lake Temiskaming (Boissonneau 1968). Other remnants of glaciofluvial activity associated with retreat of the ice front from the area include: 1) glaciolacustrine deposits of sand and gravel; nearshore and beach deposits; 2) glaciolacustrine deposits of silt and clay, minor sand; basin and quiet water deposits; 3) glaciofluvial outwash deposits of gravel and sand; and 4) glaciofluvial ice-contact deposits of gravel and sand, minor till, eskers and end moraines (Barnett et al. 1991).

Recent swamp, lake and stream deposits as well as organic deposits of peat, muck and marl can be found throughout the survey area (Born 1970; Barnett et al. 1991).

REGIONAL SAMPLING SURVEY

The current survey was conducted in June, July and August 2001 and covered a total area of approximately 3825 km^2. A total of 254 modern alluvium samples, 8 till, 1 beach deposit and 14 glaciofluvial sand (and gravel) samples were collected. Access to sample locations was achieved by truck, all terrain vehicles, boat, helicopter and float plane. As a result, the distribution of samples provides excellent regional coverage. The position of each sample was accurately recorded with a Global Positioning System (GPS) instrument and NTS map sheets.

Points of heavy mineral deposition within the streams were targeted for sample collection. These points include: the deepest part of the channel; longitudinal and point bars; and boulder, log and vegetation traps. Sample size ranged from 10 to 20 kg. Larger samples were collected at some sites to compensate for the fine-sand or silt size fraction of the sediment or for the dilution of heavy mineral grains by the high percentage of organic material found in streams in the area. Samples were sieved in the field using a 5 mm mesh screen. The <5 mm fraction of the sample has been sent for heavy mineral processing to determine the presence of kimberlite and other indicator minerals. Approximately 50 pebbles were collected from the coarser (>5 mm) fraction at each sample site, where possible, for pebble lithology classification. At each site a small portion of the stream sediment was panned and the resultant "fine-fraction" concentrate kept. Geochemical analyses for each fine-fraction sample are presently being completed. To date, pebble lithologies indicate that, typically, stream deposits are locally derived.

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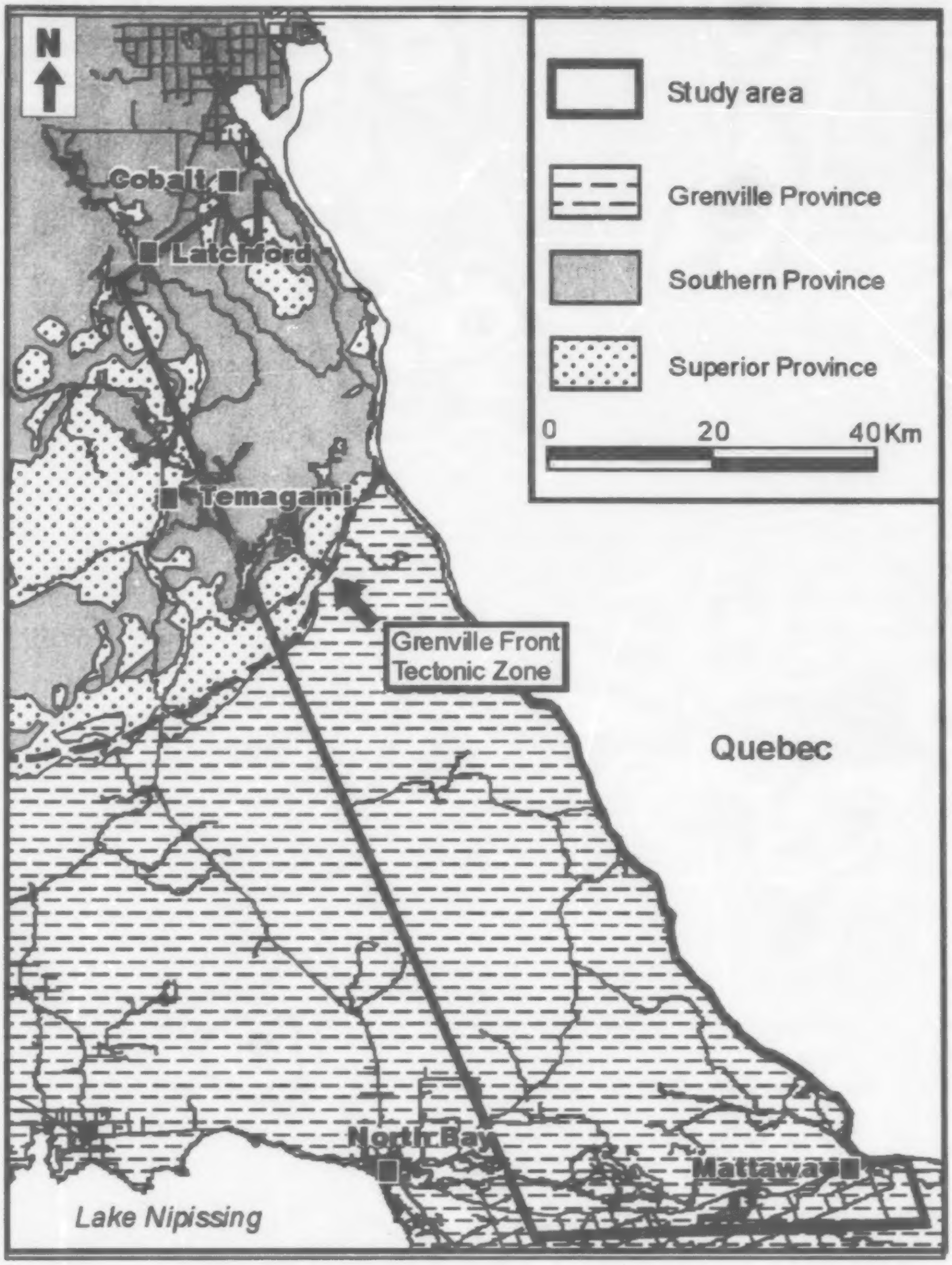
N
Cobalt
Latchford
Temagami
Grenville Front Tectonic Zone
Quebec
North Bay
Mattawa
Lake Nipissing
Study area
Grenville Province
Southern Province
Superior Province
0
20
40Km

Figure 29.1. Location and general geology map of study area.

30. Project Unit 00-35. Dayohessarah Lake Area High Density Regional Lake Sediment and Water Geochemical Survey, Northeastern Ontario

J.E. Jackson[1]

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INTRODUCTION

A helicopter supported regional lake sediment and water geochemical survey of the Dayohessarah Lake area was conducted by Sedimentary Geoscience staff from July 9 to July 27, 2001. Dayohessarah Lake is located about 90 km north of Wawa, Ontario (Figure 30.1). The survey covered all of the Dayohessarah Lake greenstone belt located between Hornepayne and White River, Ontario (Figure 30.2). This greenstone belt lies between the Kabinakagami and Hemlo greenstone belts. Lake and water samples were collected from a 3600 km^2 region that wholly encompasses the area represented on National Topographic System (NTS) map sheet 42 C/15 and portions of NTS sheets 42 F/2, 42 F/3, 42 C/10, 42 C/11 and 42 C/14. Lake sediment and/or water samples were collected at 1467 sites for an average density of 1 sample per 2.5 km^2. This lake water and sediment survey is the second part of a 2 year project to sample the Kabinakagami and the Dayohessarah greenstone belts. A survey covering the Kabinakagami greenstone belt was completed during the summer of 2000 (Jackson 2000).

BEDROCK GEOLOGY

A north trending assemblage of Archean supracrustal rocks is centered on Dayohessarah Lake which is located approximately 28 km northeast of White River, Ontario. The Dayohessarah greenstone belt is an arcuate shaped assemblage of dominantly mafic metavolcanic and metasedimentary rocks that extends over 35 km in length and up to 5 km in width. Massive to pillowed amphibolitic basalt forms the basal sequence of the greenstone belt. The basal basalt unit is overlain by local komatiitic flows, intermediate to felsic metavolcanic flows and pyroclastic rocks (Stott 1999). The youngest sequence in the belt consists of clastic metasedimentary rocks that are interlayered locally with the underlying pyroclastic rock units and unconformably overlie the komatiitic flow units.

The Dayohessarah greenstone belt is a tight syncline that plunges and opens southwards with the metasedimentary rocks occupying the core of the syncline (Stott 1999). Amphibolitic inclusions enclosed within granite pegmatite and granodioritic intrusive rocks are mapped at the southern and northern ends of the greenstone belt. These amphibolitic inclusion trains appear to discontinuously link the Dayohessarah greenstone belt with a part of the Hemlo greenstone belt to the west and the Kabinakagami greenstone belt to the east.

Mineral exploration in the Dayohessarah Lake area has focused primarily on the discovery of gold deposits. The most significant of these was the 1991 discovery of a mineralized gold zone located east of Dayohessarah Lake. The zone is up to 40 m wide and 3500 m in length and is interpreted as a high strain zone hosting gold mineralized quartz veins and quartz-feldspar sills intruding amphibolitic basaltic flows (Stott 1999).

PHYSIOGRAPHY AND QUATERNARY GEOLOGY

Most of the topography in the study area is of moderate relief with much of the terrain being bedrock controlled. The northern portion of the survey area is a dominantly flat, swampy terrain with elevations ranging from 320 to 350 m above sea level (asl). The terrain is more rugged in the southern portion of the survey area with elevations ranging from 400 to 600 m asl.

A regional compilation of the Quaternary geology (Barnett et al. 1991) indicates that most of the bedrock in the study area is covered by a thin veneer of discontinuous glacial drift. A broad area of glaciolacustrine and recent organic deposits occurs along the Shabotik River in the north (Gartner and McQuay 1980). A large area southwest of Dayohessarah Lake is covered by glaciofluvial and till deposits. Sand and gravel from outwash and ice-contact deposits are found in areas of low relief and along some of the river channels in the south. Esker deposits occur in ridges from 15 to 20 m in height and trend in a south to southwesterly direction.

SAMPLING METHODS

Where possible, organic lake sediment and water samples were collected at each lake site by 2-person teams using a float equipped helicopter. If a site contained no organic component (e.g., sand and/or clay), then, only a water sample was taken. The organic sediment was collected in a gravity corer that was lowered from the helicopter float; the sediment was then pulled to surface and deposited into a sample bag. The upper 20 cm of the sample was discarded to avoid anthropogenic bias in the geochemical data and to avoid water/sediment interface effects (i.e., increased Mn due to anoxic conditions that result in secondary accumulation of base metals). The sediment below the 20 cm depth better reflects the natural element abundance that may be attributed to the local geology. Each sample was then sealed in an airtight plastic bag in order to avoid contamination between samples.

Lake water samples were collected at a depth of 0.5 m from shallow lakes (<3 m deep) and at a depth of 2 m from deep lakes (>3 m). A semi-automated water sampling apparatus, developed by the OGS, was utilized for water collection. The apparatus consists of a submersible pump, a flow cell (for measurement of parameters such as pH, conductivity, oxidation-reduction potential and dissolved oxygen), a sample bottle tray and various hoses and pinch valves. Water is pumped from the lake and allowed to purge the sampling system prior to the collection of a water sample and the recording of water quality parameters. Water samples were kept cool after collection and processed (filtered and acidified) within 24 hours of collection.

At each site, sediment descriptions and observations were logged into a database on a pen based notebook computer. The pH, temperature, conductivity, oxidation-reduction potential and dissolved oxygen of the water samples was recorded on a YSI water quality analyzer and a GPS waypoint for the sample sites was taken.

SAMPLE PREPARATION AND ANALYTICAL PROGRAM

The organic lake sediments were placed in a breathable fabric sample bag and partially air dried in base camp prior to shipment to the analytical laboratory. The samples are freeze dried to retain any volatile elements, partially pulverized and sieved to attain a –80 (<177 μm) mesh size fraction. Laboratory analysis of the –80 mesh fraction of the organic sediments will include nitric-aqua regia digestion of 1 g of sample material followed by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma-optical emission spectrometry (ICP-OES) to determine approximately 50 trace elements. The nitric acid-aqua regia digestion technique attacks all the matrix constituents in the sample except for the silicate minerals and is therefore considered a nonselective, relatively strong partial extractant.

For each sample, approximately 15 g of prepared material will be pressed into briquettes and submitted for analysis by instrumental neutron activation (INAA) for Au and a suite of 33 other elements.

An additional 15 g of sample material will be prepared and submitted for lead fire assay followed by an ICP-MS finish for analysis of Au, Pt and Pd. Duplicates of samples and certified reference materials will be used to monitor the quality control of all analyses. Loss on ignition (LOI) is determined at 500 °C, using an automated gravimetric technique.

The water samples were filtered through a 0.45 μm syringe held filter and acidified to 1% ultrapure nitric acid within 24 hours of collection. Direct aspiration ICP-MS will be used on the water samples to analyze for approximately 50 elements including major cation and anion species. Sample duplicates, blanks and certified reference standard SLRS-4 will be used to monitor the quality control of the water analyses.

PRELIMINARY RESULTS

The average electrical conductivity (EC) for surface waters sampled from the survey is 121.8 μS/cm with samples ranging from <10 to 603 μS/cm. Figure 30.2 illustrates the range of EC values across the study area. The EC values are plotted on a base of the general geology of the Dayohessarah Lake area (Ontario Geological Survey 1991). High electrical conductivity of lake waters in uncontaminated shield terrain is largely attributable to dissolved carbonate minerals from surficial sand and gravel deposits.

The pH of the surface waters ranged from 5.46 to 9.42 with an average pH of 7.71. The pH of surface waters for the study area is shown on Figure 30.3 plotted with major surficial Quaternary deposits. The pH of lake waters shows a regional trend of neutral to slightly acidic values in the southern portion of the map area and slightly more alkaline values in the northern portion of the area. This is likely due to a thicker Quaternary drift cover in the northern part of the survey area. Some of the higher pH (alkaline) values and higher EC values occur in lakes underlain by glaciofluvial deposits and may indicate the presence of dissolved carbonate minerals in the water.

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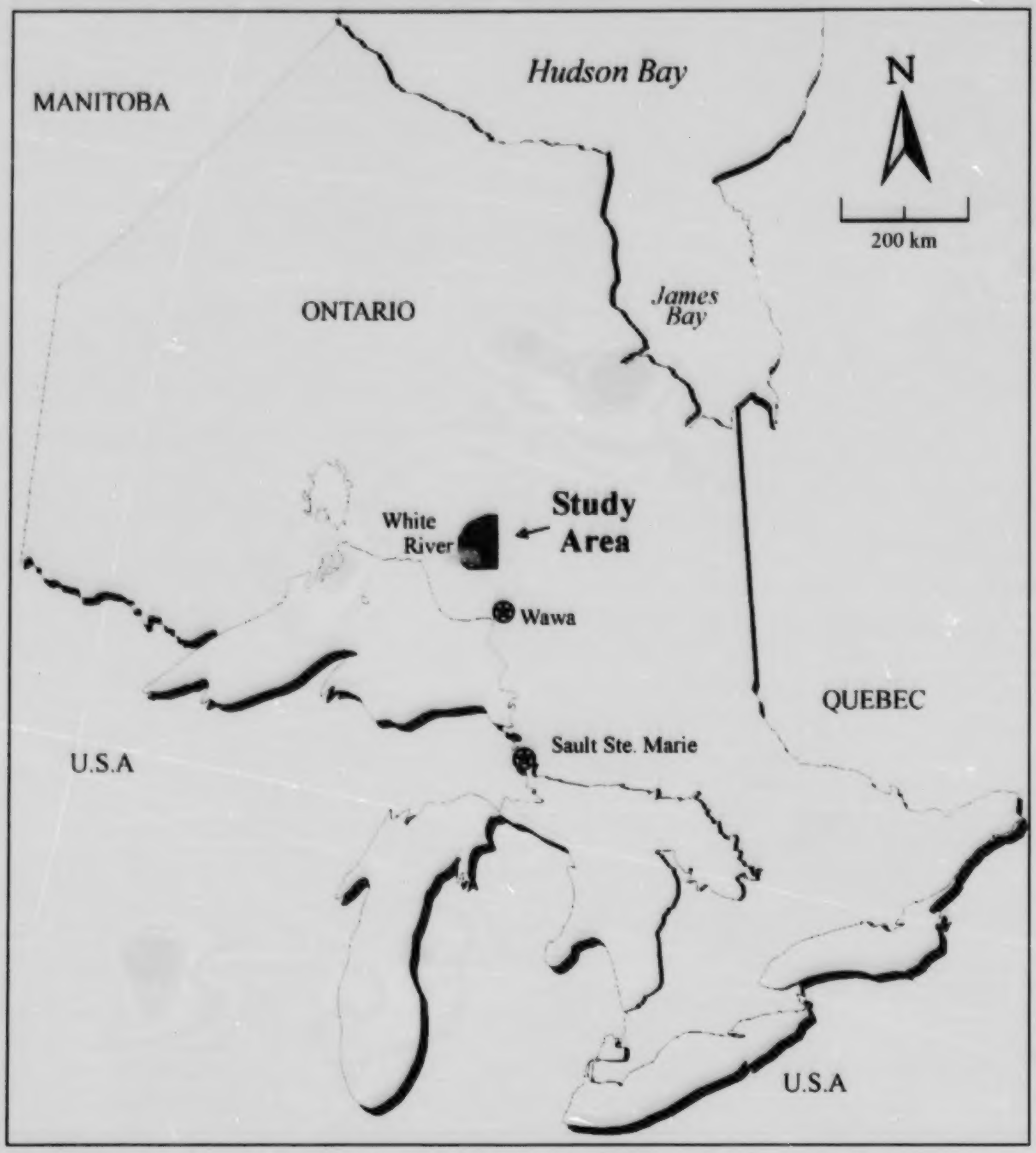
Hudson Bay
MANITOBA
N
200 km
ONTARIO
James Bay
White River
Study Area
Wawa
QUEBEC
Sault Ste. Marie
U.S.A
U.S.A

Figure 30.1. Location map of the Dayohessarah Lake area lake sediment and water geochemical survey

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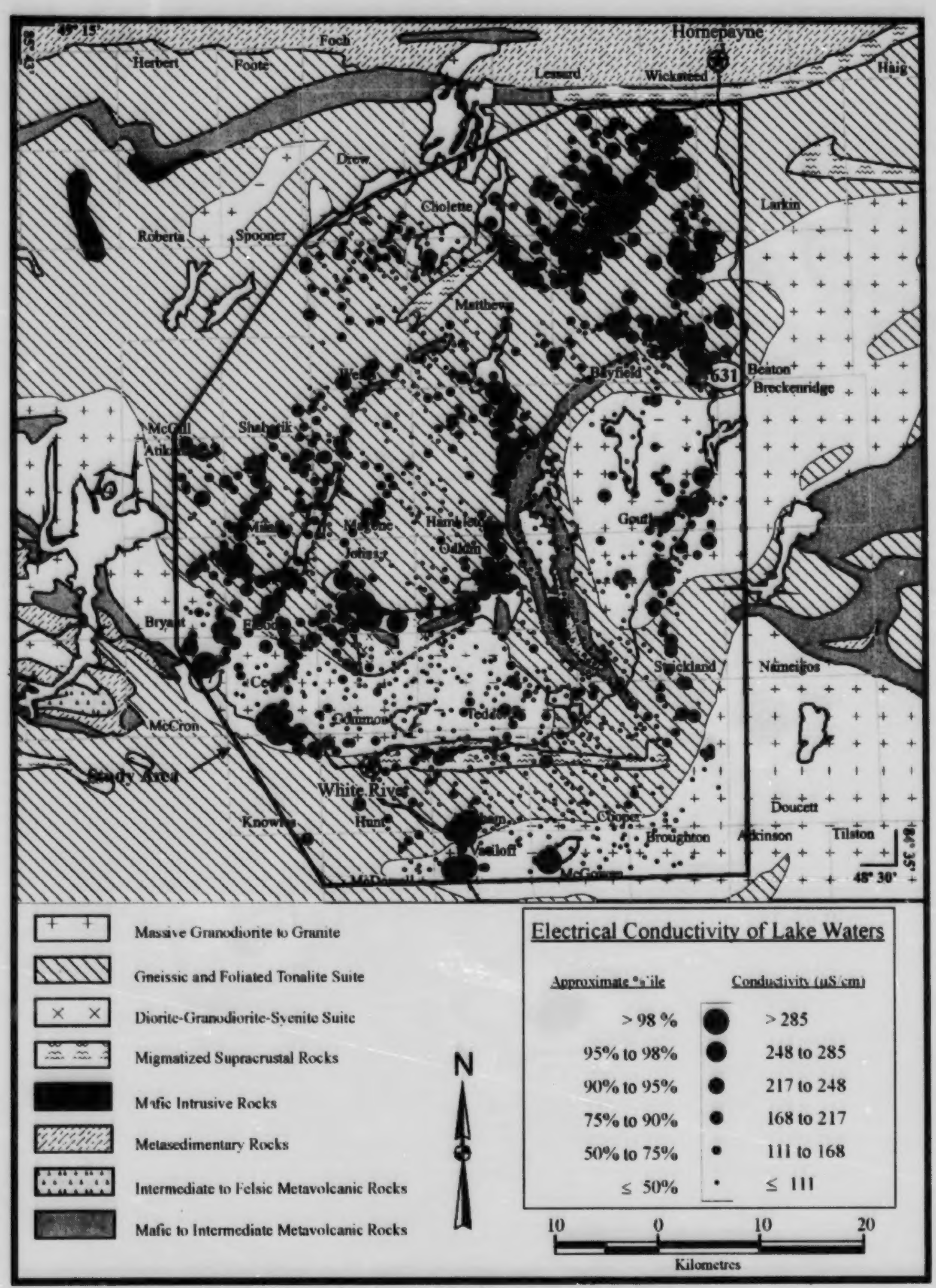
49° 15'
85° 43'
Foch
Hornepayne
Herbert
Foote
Lessard
Wicksteed
Haig
Drew
Cholette
Larkin
Roberta
Spooner
Matthews
Bayfield
631
Beaton
Breckenridge
McGill
Shabotik
Gourlay
Hambleton
Odlum
Bryant
Strickland
Nameigos
McCron
Study Area
White River
Knowles
Hunt
Cooper
Broughton
Atkinson
Tilston
Doucett
Vasiloff
McGowan
84° 35'
48° 30'
Massive Granodiorite to Granite
Gneissic and Foliated Tonalite Suite
Diorite-Granodiorite-Syenite Suite
Migmatized Supracrustal Rocks
Mafic Intrusive Rocks
Metasedimentary Rocks
Intermediate to Felsic Metavolcanic Rocks
Mafic to Intermediate Metavolcanic Rocks
N
Electrical Conductivity of Lake Waters
Approximate %'ile
Conductivity (µS/cm)
> 98 %
> 285
95% to 98%
248 to 285
90% to 95%
217 to 248
75% to 90%
168 to 217
50% to 75%
111 to 168
≤ 50%
≤ 111
10
0
10
20
Kilometres

Figure 30.2. Generalized bedrock Geology of the Dayohessarah Lake Area (after Ontario Geological Survey 1991)

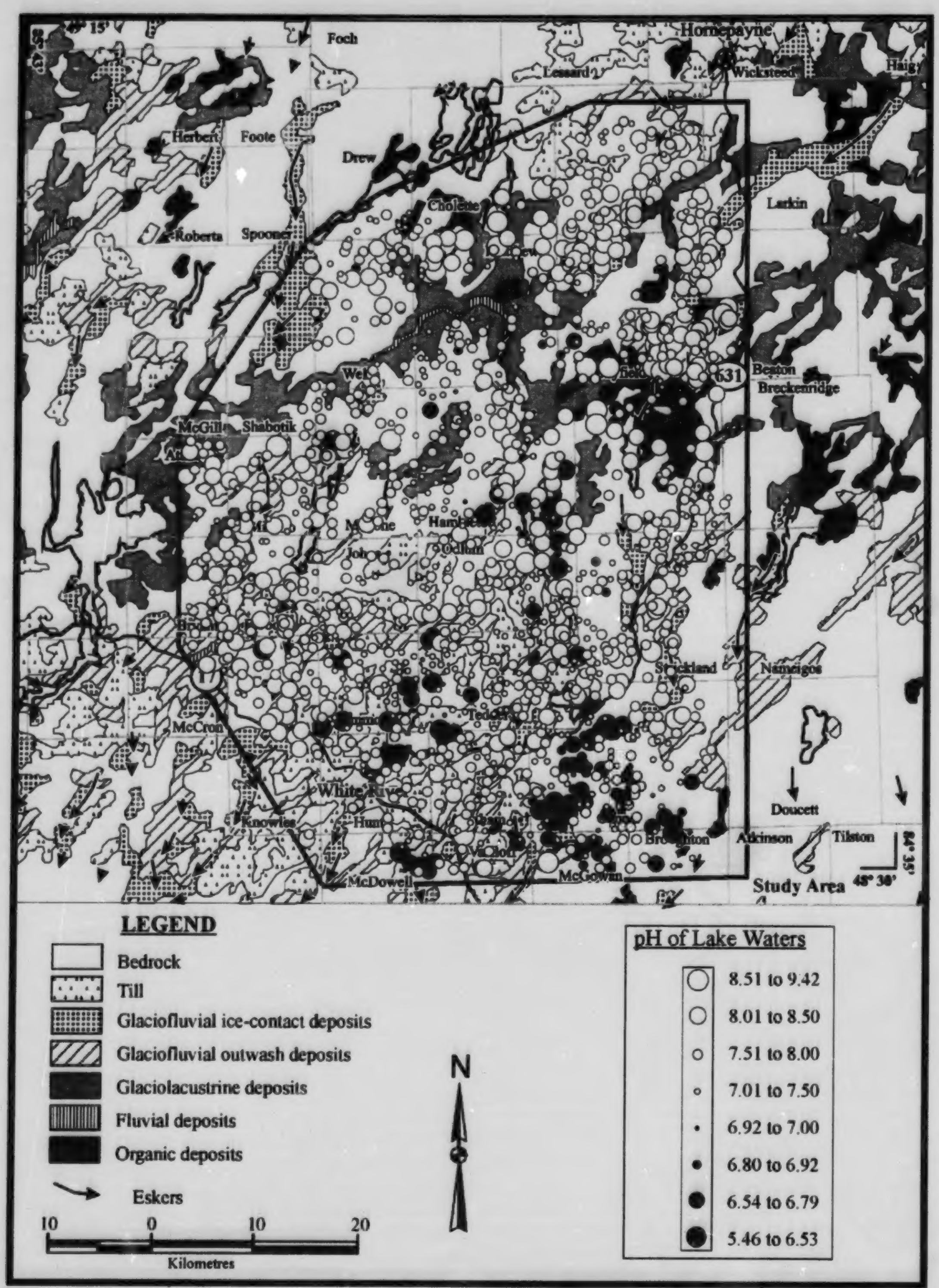
48° 15'
Foch
Hornepayne
Lessard
Wicksteed
Haig
Herbert
Foote
Drew
Cholette
Larkin
Roberta
Spooner
631
Beaton
Breckenridge
McGill
Shabotik
Hambleton
Odlum
17
Strickland
Nameigos
McCron
Tedder
White River
Knowles
McDowell
McGowan
Atkinson
Tilston
Doucett
Study Area
48° 30'
84° 35'
LEGEND
Bedrock
Till
Glaciofluvial ice-contact deposits
Glaciofluvial outwash deposits
Glaciolacustrine deposits
Fluvial deposits
Organic deposits
Eskers
10
0
10
20
Kilometres
N
pH of Lake Waters
8.51 to 9.42
8.01 to 8.50
7.51 to 8.00
7.01 to 7.50
6.92 to 7.00
6.80 to 6.92
6.54 to 6.79
5.46 to 6.53

Figure 30.3. Generalized Quaternary Geology of the Dayohessarah Lake Area (after Barnett et al. 1991)

31. Project Unit 00-039. Sturgeon Lake – Wabigoon Lake Area High Density Regional Lake Sediment and Water Survey, Northwestern Ontario

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INTRODUCTION

Fieldwork for a high-density lake sediment and water geochemical survey for the Sturgeon Lake – Wabigoon Lake area was carried out between June 4 and July 3, 2001. The survey area is located approximately 270 km northwest of Thunder Bay and covers the area represented on National Topographic System (NTS) 1:50 000 scale map sheets 52F/9, 52F/10, 52F/16, 52G/13 and 52G/14. Figure 31.1 shows the location of the survey area overlain on a base of the bedrock geology. Lake sediment and/or water samples were collected at a total of 1404 sites, giving an average density of 1 sample per 3.7 km^2.

The Sturgeon Lake – Wabigoon Lake area was selected for this type of survey for reasons including client interest in the area, geology with favourable mineral potential and minimal geochemical exploration data for the region. The National Geochemical Reconnaissance (NGR) lake sediment program carried out by the Geological Survey of Canada in the 1970s covered a region located significantly south of the study area. As a result, the current program will provide new regional geochemical data at a relatively high resolution.

REGIONAL GEOLOGIC SETTING

Bedrock Geology

The geology of the survey area is represented at a scale of 1: 253 440 on 2 Ontario Geological Survey (OGS) Geological Compilation Series maps (Breaks 1980; Blackburn 1981). Many parts of the survey area have been mapped at a scale of 1:50 000 or greater. Trowell (1983) and Trowell et al. (1983) have mapped the eastern portion of the survey area represented on NTS 1:50 000 map sheets 52G/13 and 52G/14. Portions of the central part of the survey area have been mapped by Satterly (1960) and Johnston (1969, 1972) at a scale of 1:31 680, Berger (1989, 1990) at a scale of 1:20 000 and Page (1984) at a scale of 1:15 840. More recently, Beakhouse (2000) began a multiyear mapping program to examine the geology and mineral potential of the Wabigoon area, which is partially contained in the western portion of the survey area.

In the area supracrustal rocks occur within 3 interconnected greenstone belts (Blackburn et al. 1991) comprising part of the western Wabigoon subprovince. The Sturgeon Lake greenstone belt in the east and Abram-Minnitaki Lakes greenstone belt in the central part of the area strike northeast, while the Eagle-Wabigoon-Manitou Lakes greenstone belt in the west has an arcuate outline. In general, all 3 belts consist of a lower mafic metavolcanic unit, middle mixed intermediate to felsic metavolcanic and metasedimentary units and an upper mafic to intermediate metavolcanic unit. Age dates provided by Blackburn et al. (1991) for the middle mixed units range from 2743 Ma to 2733 Ma, with one member of the South Sturgeon assemblage dated at 2718 Ma.

Significant ultramafic to mafic intrusive rocks are present in the lower mafic metavolcanic units, though many of the upper mafic sequences also contain gabbroic and peridotitic sills and dikes (Blackburn et al. 1991). These intrusive rocks may also occur at the margins of metavolcanic and granitoid intrusive rocks. Plutonic volcanism in the area consists of both synvolcanic granitoid complexes (2732 to 2708 Ma) and post-tectonic granitoid stocks emplaced between 2709 and 2685 Ma (Blackburn et al. 1991). The central part of the survey area is cut by the Wabigoon and Little Vermilion faults which strike roughly northeast from the Dryden area.

Physiography and Quaternary Geology

Engineering geology terrain maps have been produced for the area at a scale of 1:100,000 (Roed 1980; Mollard and Mollard 1980). These maps, developed mainly from the interpretation of aerial photographs, comprise the most detailed Quaternary mapping for the area. Local relief in the survey area is variable, though generally less than 40 m. Topography in the survey area is controlled by the distribution of surficial sediments and differential erosion of the underlying bedrock geology (Trowell 1983).

Glaciolacustrine clay, silt and sand of glacial Lake Agassiz form a major component of the Quaternary deposits in the area. Local thicknesses of these sediments produce areas of very gentle topography in the vicinity of Wabigoon and Dinorwic lakes, Minnitaki Lake and the English River. These lowland areas generally show a marked decrease in the density of lakes. The other significant surficial deposits in the area are the silt-, sand- and gravel-rich morainal deposits that strike southeast across the centre of the study area (Mollard and Mollard 1980). Deposits of till, glaciofluvial outwash and recent organic material (peat and muck) are thin and discontinuous throughout the area and are separated by areas of knobby and ridged bedrock.

SAMPLING METHODS

Sampling of organic lake sediments was performed using a float-equipped helicopter. An overall average of 14.8 lakes were sampled for each hour of helicopter time. The samples were collected using a gravity corer designed by the OGS. Samples were taken from depths >20 cm below the sediment/water interface (SWI) in order to minimise or avoid anthropogenic influences and SWI effects. These deeper sediments more accurately reflect the geochemical effects which may be traced back to the local geology. The samples were extruded from the collection tube into breathable fabric bags and then placed in a sealable plastic bag until the end of the sampling run.

Lake water samples were taken simultaneously with the sediment samples. On lakes <3 m deep, the samples were collected at a depth of 0.5 m below the water surface while on lakes deeper than 3 m the samples were collected at a depth of 2 m. A semi-automated water sampling apparatus, developed by the OGS, was used for the collection of samples. The apparatus consists of a submersible pump, a water quality meter (for measurement of parameters such as pH, temperature and conductivity), a sample bottle tray and a variety of hoses and valves. Water from the lake is pumped through the system in order to purge it prior to the collection of a sample and the recording of water quality data. The water samples were kept cool immediately following collection and were processed (filtered and acidified) within 24 hours of collection.

Sample site locations were recorded using a GPS receiver mounted in the cockpit of the helicopter. A customised database application operating from a pen-based computer was used to record the sediment sample information and descriptions. Water quality data was recorded using the program *Ecowatch*™.

SAMPLE PREPARATION AND ANALYTICAL METHODS

Lake sediment samples were allowed to partially air dry in porous collection bags while in the field. Upon arrival at the laboratory, the samples were freeze dried, partially pulverised in a ceramic ring mill and subsequently sieved to obtain the -80 mesh (<177 µm) size fraction. Laboratory analysis includes nitric-aqua regia digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma-optical emission spectrometry (ICP-OES) for the determination of approximately 50 trace and major elements. Nitric-aqua regia digestion attacks all sample matrix constituents except for silicate minerals and is therefore considered a non-selective, relatively strong partial extractant. Approximately 15 g of sample pulp are pressed into briquettes prior to analysis by instrumental neutron activation analysis (INAA) for Au and a suite of 34 other elements. Loss on ignition (LOI) is determined at 500°C using an automated gravimetric technique. Quality control is monitored through the use of certified reference materials placed regularly through the sample sequence and randomly taken sample pulp duplicates.

Water samples were passed through 0.45 µm syringe filters and acidified to 1% ultrapure nitric acid within 24 hours of collection. Analysis of water includes direct aspiration ICP-MS to determine approximately 50 elements. Quality of the analyses is monitored through the use of certified reference standard SLRS-4 and random sample duplicates.

PRELIMINARY RESULTS

Electrical conductivity values in lake waters in the survey area range from <10 µS/cm to 406 µS/cm, and average 49 µS/cm. Figure 31.2 shows the distribution of conductivity in lake water across the study area. As the surficial cover in the area is not extensive, bedrock geology is the primary factor contributing to these values. The average conductivity values over "greenstone" (metavolcanic and metasedimentary rocks) and granite are 64 µS/cm and 35 µS/cm, respectively.

Values for pH in lake waters range from 4.27 to 8.71 across the study area, with an average of 7.12. As with electrical conductiviy, bedrock geology is the major factor affecting pH values. Greenstone rocks show a more alkaline response (average pH of 7.33) while granitic rocks are slightly acidic (average pH of 6.93). The values of pH in lake waters are shown in Figure 31.3.

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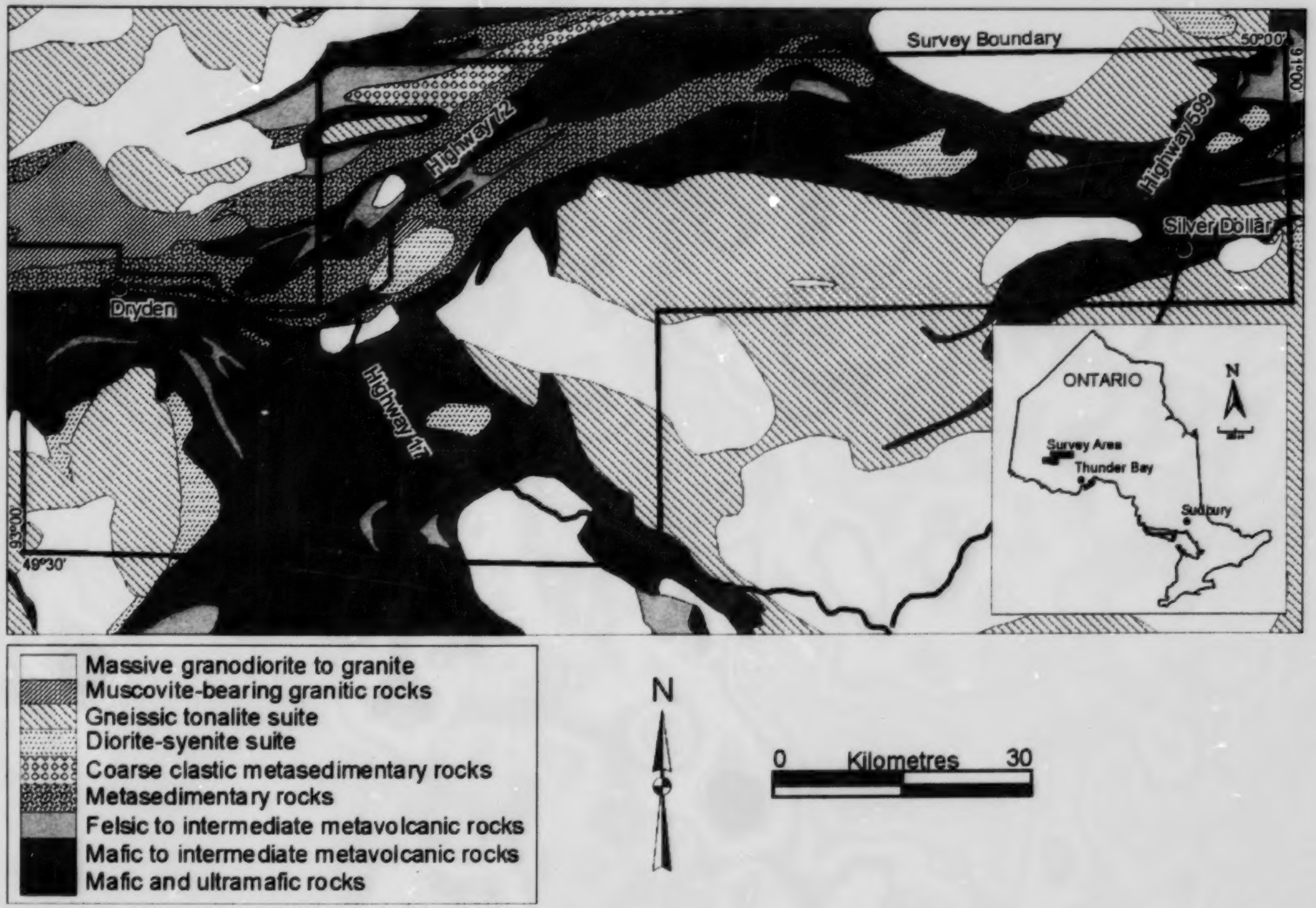
Survey Boundary
50°00'
91°00'
Highway 599
Silver Dollar
Highway 72
Dryden
Highway 17
93°00'
49°30'
ONTARIO
N
Survey Area
Thunder Bay
Sudbury
Massive granodiorite to granite
Muscovite-bearing granitic rocks
Gneissic tonalite suite
Diorite-syenite suite
Coarse clastic metasedimentary rocks
Metasedimentary rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Mafic and ultramafic rocks
N
0
Kilometres
30

Figure 31.1. Bedrock geology of the Sturgeon Lake - Wabigoon Lake area lake sediment and water geochemical survey. Geology after Ontario Geological Survey (1991).

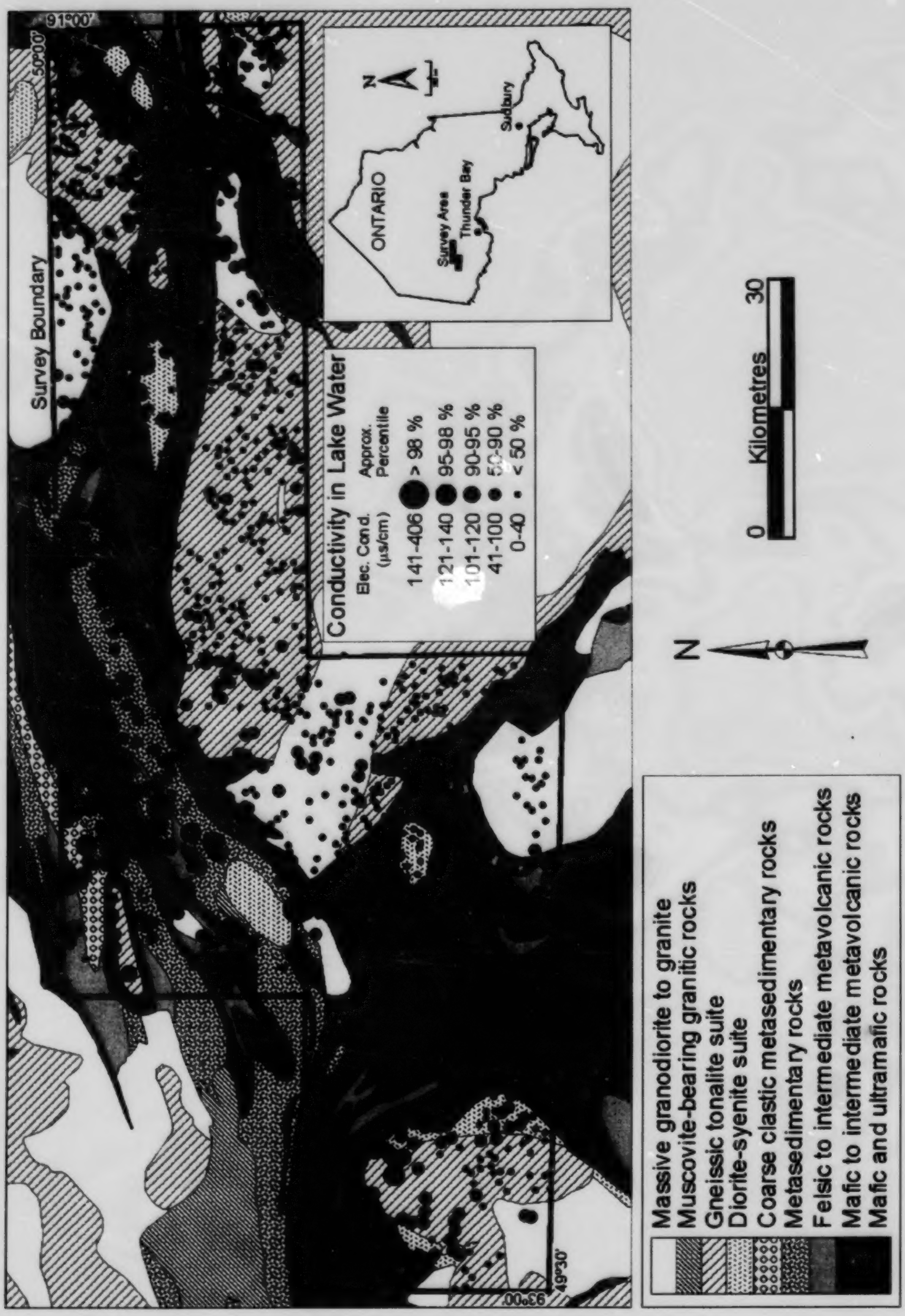
91°00'
50°00'
93°00'
49°30'
Survey Boundary
ONTARIO
Survey Area
Thunder Bay
Sudbury
N
Conductivity in Lake Water
Elec. Cond. (µs/cm)
Approx. Percentile
141-406 > 98 %
121-140 95-98 %
101-120 90-95 %
41-100 50-90 %
0-40 < 50 %
0
Kilometres
30
Massive granodiorite to granite
Muscovite-bearing granitic rocks
Gneissic tonalite suite
Diorite-syenite suite
Coarse clastic metasedimentary rocks
Metasedimentary rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Mafic and ultramafic rocks

Figure 31.2. Bedrock geology and electrical conductivity in lake waters.

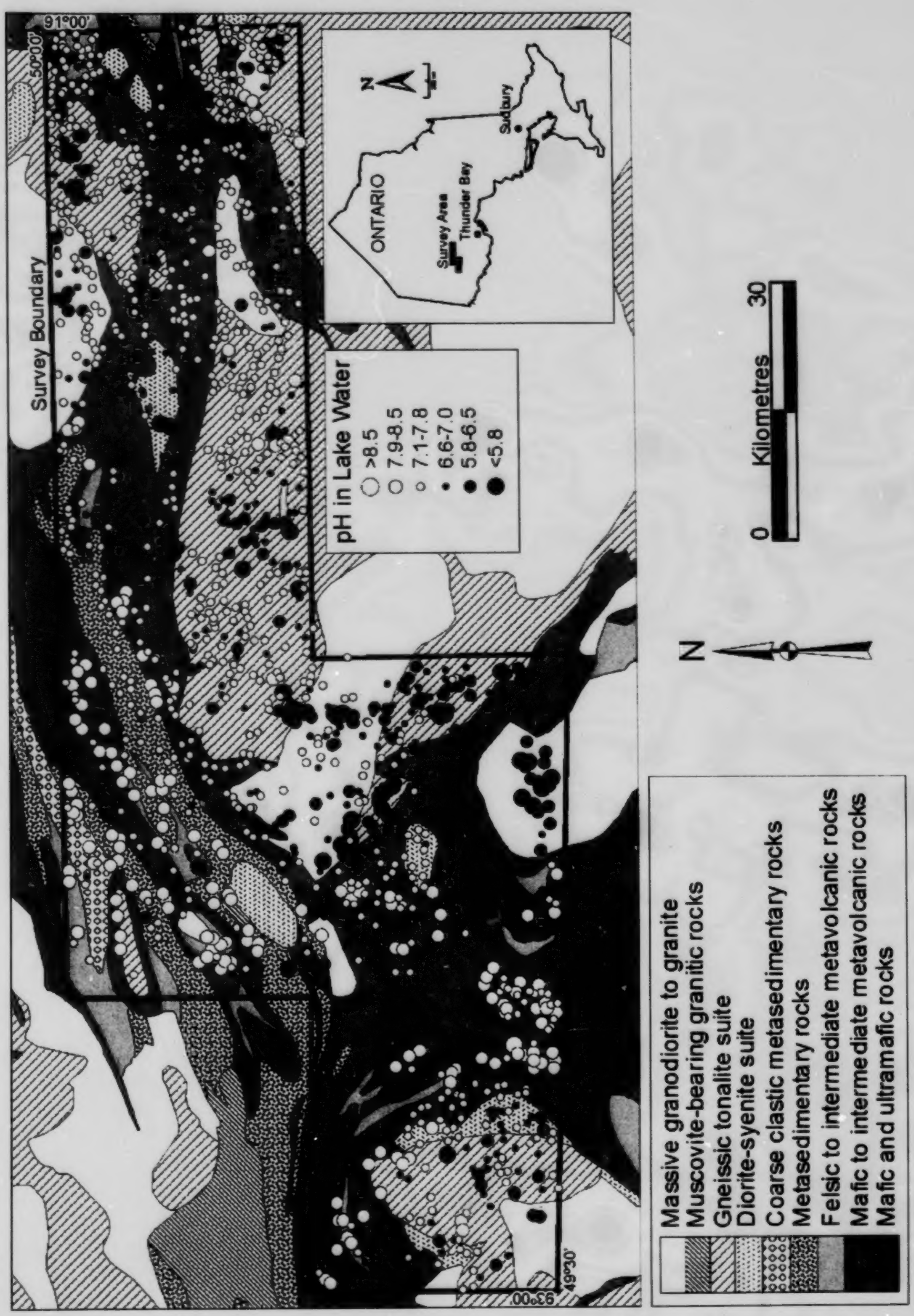
91°00'
50°00'
93°00'
49°30'
Survey Boundary
pH in Lake Water
○ >8.5
○ 7.9-8.5
○ 7.1-7.8
• 6.6-7.0
● 5.8-6.5
● <5.8
ONTARIO
Survey Area
Thunder Bay
Sudbury
N
0
Kilometres
30
Massive granodiorite to granite
Muscovite-bearing granitic rocks
Gneissic tonalite suite
Diorite-syenite suite
Coarse clastic metasedimentary rocks
Metasedimentary rocks
Felsic to intermediate metavolcanic rocks
Mafic to intermediate metavolcanic rocks
Mafic and ultramafic rocks

Figure 31.3. Bedrock geology and pH in lake waters.

32. Project Unit 00-003. Geological Investigations for Engineering Terrain Studies in Ontario's Far-North

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INTRODUCTION

Field investigations in support of the Northern Ontario Engineering Geology Terrain Studies (NOEGTs) continued during the summer of 2001. This 2-year joint Ontario Geological Survey and Canada Centre for Remote Sensing (OGS-CCRS) project attempts to undertake pilot studies designed to create terrain maps using the integration and interpretation of various types of remotely sensed imagery, digital elevation models, their derivatives and geological depositional models. This past summer, field investigations were done in 9 pilot study areas in the vicinity of Red Lake, Pickle Lake and north of Nakina, in order to verify or help in the creation of digital NOEGTs-type maps. Glacial sediment composition and distribution were also examined along the Attawapiskat River west of 86^0 W longitude. In general, the preliminary findings reported in last years "Summary of Field Work", apply to the areas investigated this past summer (Barnett and Singhroy 2000).

FINDINGS

This summer's field investigations in the Red Lake area, north of Pickle Lake and north of Nakina, indicated that these landscapes are predominantly the product of the subglacial environment. Subglacial till is the dominant sediment type deposited as ground moraine, commonly fluted or drumlinized. Large and small eskers, tunnel valleys and channels, and washboard (DeGeer?) moraine complete the subglacial landscape. Ice marginal forms, including subaqeous fans, deltas and moraines, are composed predominantly of stratified sand and gravel. Glaciolacustrine shoreline deposits of sand and gravel occur along the flanks of many of the ice marginal landforms affected by glacial Lake Agassiz. Deposits of silt and clay occur throughout the areas inundated by Lake Agassiz but are generally thicker and have greater lateral extent within topographically low areas and adjacent to sediment input sources.

In addition to the collection of field data in support of map production, several river exposures were examined along the Attawapiskat River in order to gain an understanding of material relationships with depth. The area investigated is dominated by large southward trending flutes which differ dramatically from the southwestward trending drumlinized ground moraine to the west. Observed sediment sequences are displayed graphically in Figure 32.1. Earlier investigators of the glacial stratigraphy along this part of the Attawapiskat River include Bell (1887), Prest (1963), McDonald (1969) and Thorleifson (GSC, personal communications 2001). Exposures selected for study were chosen to compliment those of previous investigators.

Prest (1963, p.5) reported the occurrence of "stratified sediments, with included plant fragments ... beneath clayey till (locally sandy) on the Attawapiskat River". Plant fragments collected from this site were dated at greater than 35 800 years B.P. (GSC-83, Dyke and Fyles 1962). The site was visited

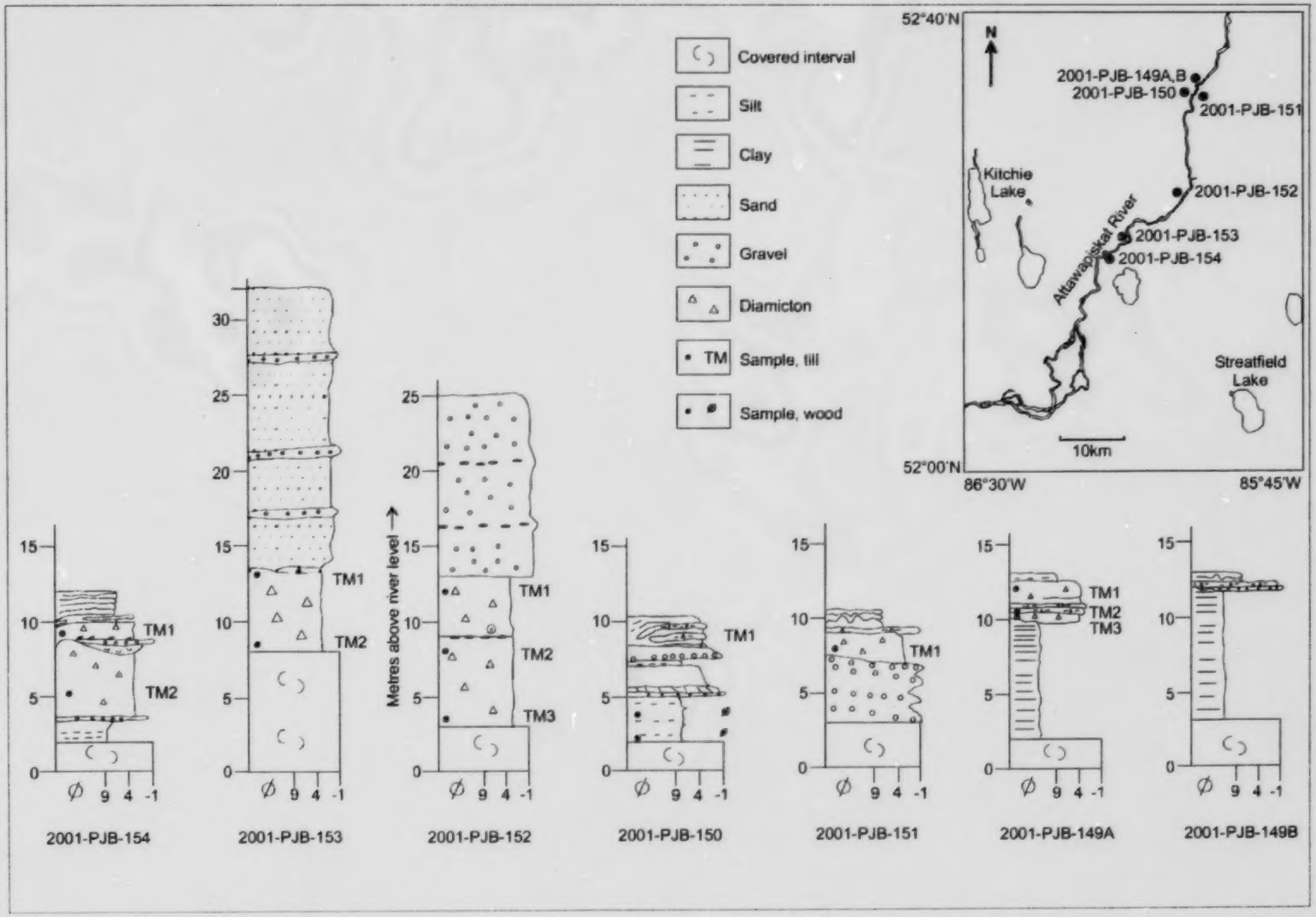
52°40'N
52°00'N
86°30'W
85°45'W
N
2001-PJB-149A,B
2001-PJB-150
2001-PJB-151
2001-PJB-152
2001-PJB-153
2001-PJB-154
Kitchie Lake
Attawapiskat River
Streatfield Lake
10km
Covered interval
Silt
Clay
Sand
Gravel
Diamicton
TM Sample, till
Sample, wood
Metres above river level →
0
5
10
15
20
25
30
Ø 9 4 -1
TM1
TM2
TM3
2001-PJB-154
2001-PJB-153
2001-PJB-152
2001-PJB-150
2001-PJB-151
2001-PJB-149A
2001-PJB-149B

Figure 32.1. Schematic sediment columns of river exposures examined along the Attawapiskat River (datum is river level).

Table 32.1. Matrix grainsize and carbonate analysis of diamicton units.

Sample	Easting	Northing	Material Interpretation	%Sand	%Silt	%Clay	Mean grainsize in microns	% Carbonate in matrix	Cacite:Dolomite Ratio in matrix
2001-PJB-149-TM1	567062	5828424	till (subglacial)	63	35	2	97	69.8	3.2
2001-PJB-149-TM2	567062	5828424	debris flow	61	38	1	90	46.1	5.8
2001-PJB-149-TM3	567062	5828424	debris flow	50	45	5	53	24.7	4.1
2001-PJB-150-TM1	566080	5826707	debris flow	68	31	1	118	45.2	3.9
2001-PJB-151-TM1	566757	5826962	till (subglacial)	52	41	7	59	44.6	4.8
2001-PJB-152-TM1	564897	5811095	till (subglacial)	42	49	9	39	41.9	4.9
2001-PJB-152-TM2	564897	5811095	till (subglacial)	43	44	13	32	40.1	6.7
2001-PJB-152-TM3	564897	5811095	till (subglacial)	39	46	15	27	41.4	7.7
2001-PJB-153-TM1	556052	5804518	till (subglacial)	42	49	9	34	41.0	5.5
2001-PJB-153-TM2	556052	5804518	till (subglacial)	47	45	8	48	41.6	4.8
2001-PJB-154-TM1	552371	5801842	till (subglacial)	45	45	10	39	45.9	4.1
2001-PJB-154-TM2	552371	5801842	till (subglacial)	43	46	11	35	38.7	5.6

Table 32.2. Pebble lithology of diamicton units (all figures in percent).

Sample	Felsic igneous	Mafic igneous	Metamorphic	Meta-sedimentary	Limestone	Dolostone	Clastic	Total PreCambrian	Total Paleozoic	Striated
2001-PJB-149-TM1	0	0	0	0	2	98	0	0	100	n/a
2001-PJB-149-TM2	0	9	0	30	0	61	0	39	61	4
2001-PJB-149-TM3	5	3	0	22	17	53	0	30	70	3
2001-PJB-150-TM1	0	8	0	38	29	25	0	46	54	8
2001-PJB-151-TM1	3	0	5	50	12	30	0	58	42	12
2001-PJB-152-TM1	9	0	0	31	30	30	0	40	60	22
2001-PJB-152-TM2	0	0	0	55	32	13	0	55	45	13
2001-PJB-152-TM3	4	1	0	37	51	4	0	45	55	15
2001-PJB-153-TM1	5	0	2	54	26	10	3	61	39	10
2001-PJB-153-TM2	12	0	0	37	49	0	2	49	51	12
2001-PJB-154-TM1	13	10	0	30	47	0	0	53	47	13
2001-PJB-154-TM2	2	0	0	43	43	12	0	45	55	14

and the exposed sediment sequence examined (2001-PJB-150, Figure 32.1). The plant fragments, small flattened pieces of wood, occur within the silt parts of 2 stratified gravel to silt sediment cycles thought to have been deposited during the infilling of cut-off meanders in a meandering stream system. Based on this interpretation, the sediments could have been deposited during the Sangamon and be as old as 110 ka. No till (subglacially deposited) was observed at the site above the organic-bearing sediment, making correlation to adjacent river exposures difficult. However, thin interbedded layers and lenses of diamicton (debris flows of probable glacial origin, flowtills), silt and sand, cap the exposure which may aid in correlation.

Adjacent sections expose 1 or 2 layers of subglacial till separated by stratified sediments or boulder pavements. Some results of analysis for samples collected from the river exposures examined are provided in Table 32.1 and 32.2. Till samples taken south of the organic-bearing exposure have similar grainsize distribution curves. The distribution curves consist of 3 peaks, in the sand, coarse silt and clay size fractions that indicate the incorporation of Precambrian shield lithologies, carbonate rocks of the Hudson Bay lowland and pre-existing fine-grained sediment of probable glaciolacustrine origin. The glacier that traversed both areas of Precambrian and Paleozoic bedrock, probably re-advanced into an existing glacial lake, incorporating the fine-grained sediments, to produce the observed grainsize distributions. It was not possible to determine the relationship between the southerly-trending fluted terrain and the southwesterly-trending drumlinized terrain at the river exposures examined. All subglacial till layers observed are presently thought to have been deposited by ice flowing from the north. This interpretation is supported by clast fabric work done by Thorleifson on adjacent exposures (GSC personal communication 2001). The thick glaciofluvial sand and gravel deposits at exposures 2001-PJB-152 and 2001-PJB-153 are part of an esker system that probably formed during the final stages of deglaciation of the area.

Ground data collected during the field season will assist in image analysis and the interpretation of derived products. Important steps toward the creation of NOEGTs-type maps for Ontario's far-north.

ACKNOWLEDGEMENTS

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33. Project Unit 01-013. A Seamless Quaternary Geology Map of Southern Ontario

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INTRODUCTION

Increased pressures arising from urban development have resulted in an expanding need for information on the distribution and character of both surface and subsurface sediments in southern Ontario. Soils developed on these sediments are amongst the best in the world for growing crops. Deposits of high quality sand and gravel, as occur within many of the glacial deposits in southern Ontario, are important sources of construction aggregate and extremely valuable, especially when located close to market. Thick deposits of impermeable clays contain and protect us from municipal and industrial landfill leachate and buried deposits of permeable sand and gravel form important aquifers from which many urban areas draw their potable drinking water. Conservation authorities, amongst others, are becoming increasingly more reliant on high quality geological information for water budget modelling and management. A knowledge of the inherent properties of the unconsolidated deposits that overlie bedrock in southern Ontario assists with the recognition of potential hazards associated with construction on or adjacent to sensitive ground.

It is becoming increasingly clear that information regarding the Quaternary geology of southern Ontario must be readily accessible and in a format that is easily understood by the public. The Land Information Ontario (LIO) project (Land Information Ontario 2001), which is an Ontario Government-Land & Resource Cluster (LRC) initiative spearheaded by the Ministry of Natural Resources (MNR), is a first attempt to bring data concerning lands and resources within the province into a digital warehouse available over the Internet. Housed within this warehouse is information regarding property boundaries and ownership, zoning, mining lands, population, topography, roads, infrastructure as well as information on the water, soils, geology and biota present within the province. A detailed, seamless map of Quaternary geology for southern Ontario will form one of these layers of information within the LIO warehouse. This summary contains an overview of the sources of information that will be used for the generation of the seamless map, an outline of the steps followed during data automation, a brief description of the methods employed for the generation of the attributed seamless map, a summary of ongoing data modelling activities, and finally, a list of the potential resulting products.

This project is funded under the Water Resources Inventory Program (WRIP) of the MNR as well as under new funding to the Ministry of Northern Development and Mines, recently announced by the Government of Ontario. Data modelling and analysis is supported in kind through LIO as well as by staff of the Geological Survey of Canada (GSC). Digital map products authored by the GSC were contributed towards this project as well.

DATA SOURCES & AUTOMATION

The area covered by this project contains approximately 150 complete and partial 1:50 000 scale National Topographic System (NTS) map sheets (Figure 33.1). The northern limit of the compilation roughly extends from Key Harbour on Georgian Bay eastward to Chalk River on the Ottawa River valley. Published 1:50 000 scale Quaternary maps are available for most of the project area. Detailed information is not available for about 6 NTS map sheets in south-central Ontario (Figure 33.1).

Quaternary mapping was undertaken by both the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC) over the last 40 years. GSC mapping is concentrated primarily in eastern Ontario as well as within the Oak Ridges Moraine north of Lake Ontario. Most of the GSC data is available in digital vector format which will be translated into the LIO data standard. OGS data is available in both vector and raster formats. Digitizing of vector OGS maps was undertaken primarily during the ERLIS (Earth Resources Land Information System) data capture process. Most of the preliminary maps within southern Ontario are available as raster images. These images were rubber sheeted to the Natural Resources and Values Information System (NRVIS) geographic base information and sent to the Sault Ste. Marie Innovation Centre for heads-up digitizing following a standard defined by an OGS, MNR and LIO working group. Funding for the automation process was provided by the MNR under the WRIP.

GENERATION OF A SEAMLESS ATTRIBUTED MAP

Polygonal information and line and point symbology were captured as part of the automation process. All polygons are tagged with a geological unit number that is linked to the map legend. Information extracted from the map legend include a description of the material type and its age. This information is included in the attribute tables for each map.

A visual inspection of legends for all maps was undertaken to assist with the development of a provincial legend suitable for a 1:50 000 scale compilation. The provincial legend consists of 21 map units some of which are subdivided. This legend is still under development and may change as the project develops. A table containing a column with the original map unit number and a second column with its provincial legend equivalent was created for each map sheet within southern Ontario. Additional attributes extracted from the legend of each map sheet and attached to this table include: 1) map name; 2) source map scale; 3) primary material; 4) primary material modifier; 5) secondary material; 6) primary genesis; 7) primary genesis modifier; 8) veneer; 9) age; 10) stratigraphic modifier; 11) provenance; 12) carbonate content; 13) formation name; and 14) permeability. Each polygon within a given map may contain an entry for some or all of the above listed attributes. Some of the attributes could be used to generate derivative maps suitable for a variety of applications. For example, a primary materials map could be generated irrespective of depositional environment to determine the location of all gravel deposits for aggregate resource evaluation or clay deposits for landfill siting.

Single entries within attribute columns are desired for effective querying in a Geographic Information System (GIS). In some cases, a particular map unit within a given map legend could include more than one primary material, primary material modifier, primary genesis or primary genesis modifier. Additional attribute columns were created and populated with single attributes based on a "best guess" of what is the dominant attribute within the given map unit. For example, the primary material for map unit 8a within a given area may be defined as silt and clay. To avoid multiple entries within the primary material field, we have chosen to replace silt and clay with silt. We believe that in most cases, this rule will stand. Field checking of some polygons will be required to determine their single attribute values.

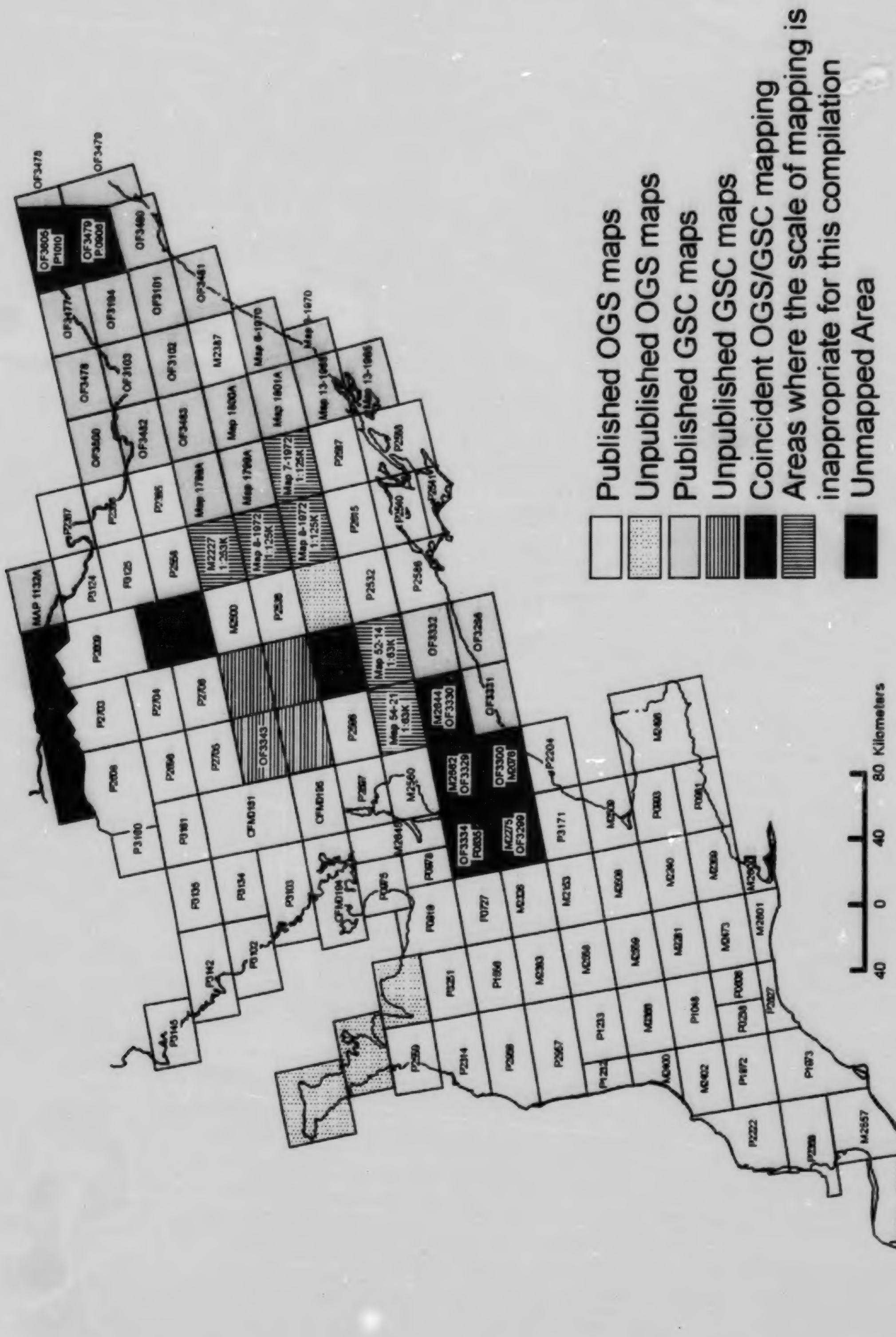
Published OGS maps
Unpublished OGS maps
Published GSC maps
Unpublished GSC maps
Coincident OGS/GSC mapping
Areas where the scale of mapping is inappropriate for this compilation
Unmapped Area
40
0
40
80 Kilometers

Figure 33.1. Index map of Quaternary geology for southern Ontario highlighting source information.

All attribute legend translation tables were appended to each other to create a master translation table for all of southern Ontario. The map numbers and original deposit type codes were concatenated to create a key attribute unique to each map sheet unit that could be joined to the attribute tables associated with each map sheet. A similar key identifier column consisting of the map number and map unit number was inserted into the attribute table of each map and is the basis for the table join. The polygons of each map can then be classified according to the provincial legend or any of the derived attributes to create a tiled product with consistent attribution.

Boundary faults exist between the individual map tiles for most attributes. Some of these boundary faults will be corrected using topographic information. Others will require some field checking to confirm or adjust geologic boundaries. Field checking will also be required to establish the identity of unlabeled polygons on source data as well as to establish the single entry attributes of selected polygons.

DATA MODELLING ACTIVITIES

A data model is defined as a representation of data and its structure as it may be stored in a computer system. Early in the project, OGS and MNR staff defined the ArcInfo coverages and attribute tables that would be used for digitizing. Previously digitized data were converted to use the same standard coverages and attribute tables as the current digitizing, so that all individual digital maps will have a consistent data format and structure.

OGS, LIO, MNR and GSC staff formed a working group to discuss possible data models for handling the Ontario Quaternary geology data. The GSC staff are also working on the North American Geological Data Model (NADM) (Johnson et al. 1999). The Quaternary part of the NADM is still being developed, and the attributes and science language developed in creating the Ontario seamless Quaternary geology map are being considered in developing the NADM for Quaternary geology.

The NADM will provide a standard way of storing and integrating geological data of differing ages, scales, and origins, for geological compilations and Internet presentation of data. The Ontario seamless Quaternary geology map will be compatible with the NADM.

MAP PRODUCTS

Several distinct map products may be available as a result of this project. The automation of monochrome preliminary maps will allow for the release of coloured final maps thus completing a full set of coloured, Quaternary geology maps for southern Ontario. These maps will each contain their unique legends making comparison with adjoining maps difficult. By joining the provincial attribute table to the attribute tables linked to individual maps, it is possible to generate a series of tiled attribute maps with consistent legend and attribute classification. Office and field-based adjustments of boundary faults between maps will allow for the construction of a tile-based seamless map of southern Ontario. The neatlines between maps are preserved in this product and allow for the maintenance of map specific attributes. Polygons within individual map sheets that are merged as a result of translation to the provincial standard retain their polygonal subdivision and attribution. The generation of a "true" seamless map results by dissolving these internal polygonal boundaries as well as those between individual map sheets. By doing this, attributes unique to individual map sheets are lost. A new attribute table will be constructed that is linked to the provincial legend for this seamless map. Generic entries for primary material, genesis, age, permeability, etc. will be associated to this table.

TIMETABLE

Data automation, data quality checks and the translation of attribute tables to a provincial standard is expected to be completed by March, 2002. A complete cover with no gaps or overlaps is expected to be available at this time as well. Field checking and the generation of a seamless product is expected to be undertaken during the 2002-2003 fiscal year.

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34. Project Unit 01-306. Sedimentary Geoscience Observations Database Project

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INTRODUCTION

The Sedimentary Geoscience Section (SGS) has over the years generated large volumes of project-related data, including lake sediment and lake water geochemistry, indicator mineral data, and overburden geochemistry. The Sedimentary Geoscience Observations (SGO) database project will bring together much of this data in an accessible, digital format.

The SGO data will be brought together in a database server located at the Ministry of Northern Development and Mines (MNDM) in Sudbury. The data will also reside in the Internet-Accessible Land Information Ontario (LIO) data warehouse (Land Information Ontario 2001). Public access to the data will be provided by LIO.

By September 2001, data analysis for this project had been completed and a database had been constructed for use in converting and bringing together data. It is the intention of the Sedimentary Geoscience Section (SGS) to proceed with data conversion and loading of the ministry's SGO server database with all existing digital data.

DATA

The SGO database will hold much of the Sedimentary Geoscience Section's "point" data. It will hold descriptive information pertaining to geological observations obtained at a "station", such as a sample pit or natural exposure, and the related sample information and analytical results.

Much of the data collected by the SGS since the 1980s is available in digital form as project-specific Miscellaneous Release Data (MRD) publications. Data organization varies among MRDs, because of the differing subject matter, different study areas and evolving technologies. The SGO database will unify the data and allow data from different project areas to be used together with relative ease.

DATA ANALYSIS

A team of Land Information Ontario and MNDM staff completed the data analysis starting in February, 2000. J. Ernsting of LIO led the analysis. R. Kelly and S. van Haaften represented MNDM, and W. Hayes and A. Trudell participated from LIO.

The analysis first determined the nature and scope of the data. The data exist in digital MRD publications and in older, hard copy publications. The older, hard copy publications were declared out of scope for the first SGO data loading efforts, although they may be loaded at a future date. Each digital data publication accompanies one or more hard copy reports that describe the sampling and analytical procedures and highlight significant results. Forty-seven existing MRD data publications were identified by January 2001 for loading into the database. The data include over 800 000 lake sediment analytical results, over 350 000 lake water analytical results and a large but uncounted quantity of overburden geochemistry and indicator mineral data.

A data model is defined as a representation of data and its structure as it may be stored in a computer system. The analysis team created a draft data model and presented it to groups of interested people at client consultation meetings. Staff of the Geological Survey of Canada (GSC) participated in the first client consultation meeting and presented the data model developed for a GSC geochemical database (Adcock et al. 2001).

Client suggestions were recorded and the data model was further refined to ensure compatibility with the GSC data model. It was still a logical data model which needed further work to develop a "physical" data model implemented as an SGO database that can be used for data conversion and storage. This task was completed by S. van Haaften at MNDM in the spring of 2001 using the Microsoft ® Access ® database management system.

DATA MODEL

As previously mentioned, a data model can be defined as a representation of data and its structure as it may be stored in a computer system. A data model consists of a data model diagram that shows entities and their relationships, and a data dictionary explaining the entities and their attributes. Data modeling references include Chen (1977) and Harrington (1998).

The SGO database model as implemented in Microsoft Access is shown in Figure 34.1. It has similarities to Ontario's lithogeochemistry database and to the GSC's surficial geochemistry database.

The individual boxes in the data model represent database tables and the lines between boxes represent the relationships among tables. In the following notes, tables are italicized. Data are created by or sourced from *projects*, *publications* and *individual* geoscientists. Therefore the *station*, *material sample* and *testing subsample* tables are related to these data source tables so that it can be determined where the data came from.

For overburden, lake water, or lake sediment geochemistry, samples are submitted in an *analytical batch*; there is *quality control summary* information about the batch, and there are *geochemistry* results. There are also *expected results* for standard reference material samples analyzed for use in quality control.

In many overburden and modern alluvium sampling surveys, the nature of mineral grains and their geochemistry are recorded. These data are recorded in the *mineral geochemistry*, *mineral grain counts*, *sample processing*, *sample processing remarks*, *gold grain details* and *gold calculated* tables. A *pebbles* table holds the results from counts of different pebble types and a *grain size* table holds grain size test results.

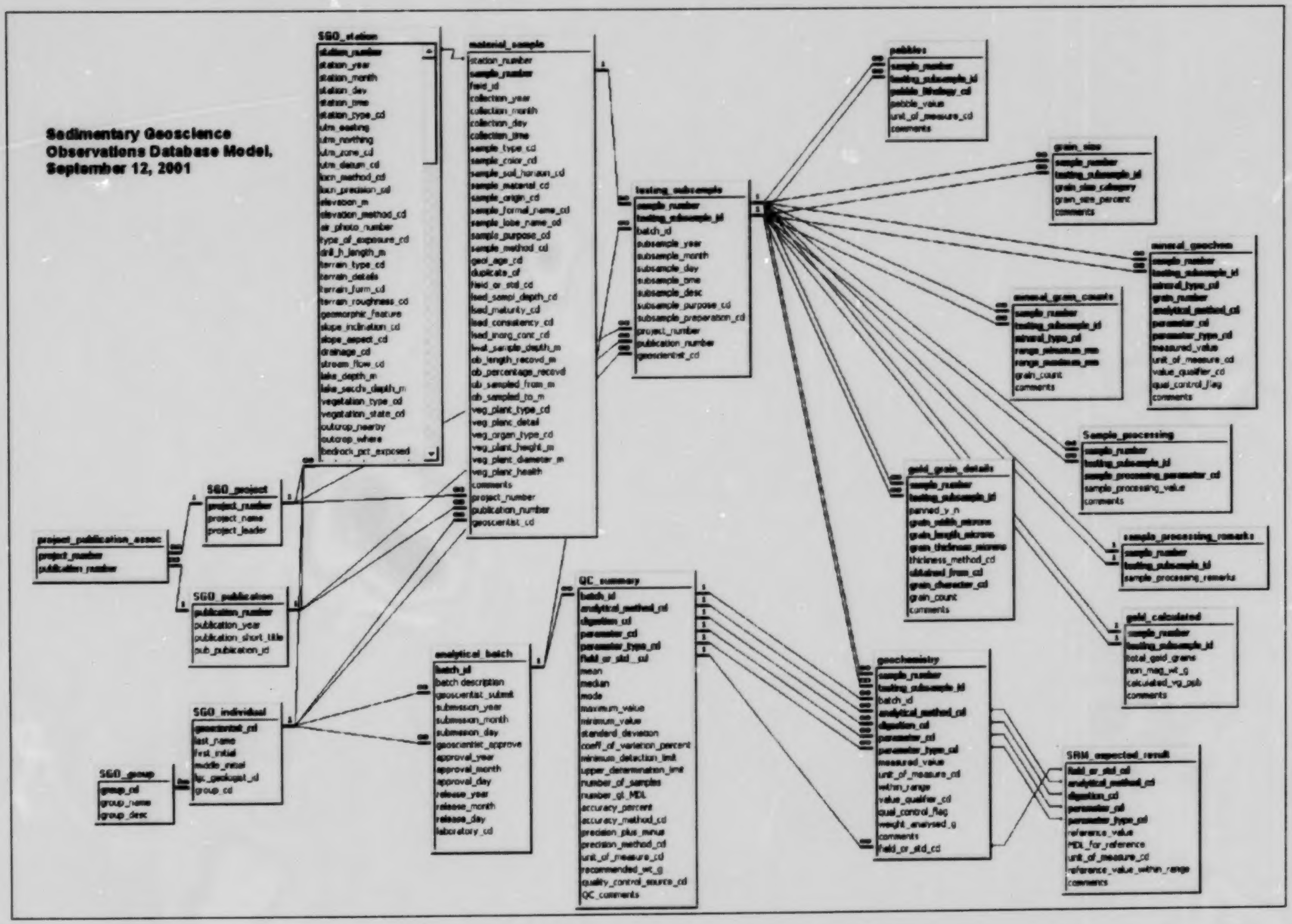
Sedimentary Geoscience
Observations Database Model,
September 12, 2001
SGO_station
station_number
station_year
station_month
station_day
station_time
station_type_cd
utm_easting
utm_northing
utm_zone_cd
utm_datum_cd
loc_method_cd
loc_precision_cd
elevation_m
elevation_method_cd
air_photo_number
type_of_exposure_cd
drill_h_length_m
terrain_type_cd
terrain_details
terrain_form_cd
terrain_roughness_cd
geomorphic_feature
slope_inclination_cd
slope_aspect_cd
drainage_cd
stream_flow_cd
lake_depth_m
lake_secchi_depth_m
vegetation_type_cd
vegetation_state_cd
outcrop_nearby
outcrop_where
bedrock_pct_exposed
material_sample
station_number
sample_number
field_id
collection_year
collection_month
collection_day
collection_time
sample_type_cd
sample_color_cd
sample_soil_horizon_cd
sample_material_cd
sample_origin_cd
sample_formal_name_cd
sample_lobe_name_cd
sample_purpose_cd
sample_method_cd
geol_age_cd
duplicate_of
field_or_std_cd
lsed_sampl_depth_cd
lsed_maturity_cd
lsed_consistency_cd
lsed_inorg_cont_cd
fwat_sample_depth_m
cb_length_recovd_m
cb_percentage_recovd
cb_sampled_from_m
cb_sampled_to_m
veg_plant_type_cd
veg_plant_detail
veg_organ_type_cd
veg_plant_height_m
veg_plant_diameter_m
veg_plant_health
comments
project_number
publication_number
geoscientist_cd
testing_subsample
sample_number
testing_subsample_id
batch_id
subsample_year
subsample_month
subsample_day
subsample_time
subsample_desc
subsample_purpose_cd
subsample_preparation_cd
project_number
publication_number
geoscientist_cd
pebbles
sample_number
testing_subsample_id
pebble_lithology_cd
pebble_value
unit_of_measure_cd
comments
grain_size
sample_number
testing_subsample_id
grain_size_category
grain_size_percent
comments
mineral_geochem
sample_number
testing_subsample_id
mineral_type_cd
grain_number
analytical_method_cd
parameter_cd
parameter_type_cd
measured_value
unit_of_measure_cd
value_qualifier_cd
qual_control_flag
comments
mineral_grain_counts
sample_number
testing_subsample_id
mineral_type_cd
range_minimum_mm
range_maximum_mm
grain_count
comments
Sample_processing
sample_number
testing_subsample_id
sample_processing_parameter_cd
sample_processing_value
comments
gold_grain_details
sample_number
testing_subsample_id
panned_y_n
grain_width_microns
grain_length_microns
grain_thickness_microns
thickness_method_cd
obtained_from_cd
grain_character_cd
grain_count
comments
sample_processing_remarks
sample_number
testing_subsample_id
sample_processing_remarks
gold_calculated
sample_number
testing_subsample_id
total_gold_grains
non_mag_wt_g
calculated_vg_ppb
comments
geochemistry
sample_number
testing_subsample_id
batch_id
analytical_method_cd
digestion_cd
parameter_cd
parameter_type_cd
measured_value
unit_of_measure_cd
within_range
value_qualifier_cd
qual_control_flag
weight_analysed_g
comments
field_or_std_cd
SRM_expected_result
field_or_std_cd
analytical_method_cd
digestion_cd
parameter_cd
parameter_type_cd
reference_value
MDL_for_reference
unit_of_measure_cd
reference_value_within_range
comments
QC_summary
batch_id
analytical_method_cd
digestion_cd
parameter_cd
parameter_type_cd
field_or_std_cd
mean
median
mode
maximum_value
minimum_value
standard_deviation
coeff_of_variation_percent
minimum_detection_limit
upper_determination_limit
number_of_samples
number_gt_MDL
accuracy_percent
accuracy_method_cd
precision_plus_minus
precision_method_cd
unit_of_measure_cd
recommended_wt_g
quality_control_source_cd
QC_comments
analytical_batch
batch_id
batch description
geoscientist_submit
submission_year
submission_month
submission_day
geoscientist_approve
approval_year
approval_month
approval_day
release_year
release_month
release_day
laboratory_cd
SGO_project
project_number
project_name
project_leader
project_publication_assoc
project_number
publication_number
SGO_publication
publication_number
publication_year
publication_short_title
pub_publication_id
SGO_individual
geoscientist_cd
last_name
first_initial
middle_initial
gsc_geologist_cd
group_cd
SGO_group
group_cd
group_name
group_desc

Figure 34.1. SGO database model

DATA FLOW

Once the initial data load of the SGO database is completed, the OGS will continue to publish a digital MRD publication for each new project in a timely fashion. Eventually project data may be loaded directly to, and published from, the SGO database.

Data from each MRD will be loaded into the SGO database which will be hosted in the Oracle database management system on MNDM's Data Acquisition Server (DAS). The DAS repository can be used by MNDM staff to export custom subsets of data for in-house data compilation and analysis projects, but it is intended that the LIO data warehouse should be the public access gateway to the data.

The LIO data warehouse uses Oracle ® and ESRI ® SDE ® software to manage data. Database tables will exist within LIO to hold the SGO data and they will be periodically updated from the DAS. LIO will offer the following ways for clients to access the data. Initially, there will be a map and database browser in which data can be visualized on the Internet. This browser currently exists for non-SGO data sets (Land Information Ontario 2001). In the future, LIO will offer a data subscription service for downloads and a capability to order hard copy reports and digital MRDs.

PHYSICAL DATABASE

To test whether existing data could be successfully loaded into the Access database, one lake water and lake sediment geochemistry survey from MRD 17 (Hamilton et al. 1995) was selected. The data was successfully loaded and subsequently all data was loaded from MRD 34 (Morris 1998), an indicator mineral survey. The database design was modified substantially from the draft logical model during the testing to accommodate the MRD data. The station and sample tables were also modified to suit a revised Palm III ® / Pendragon Forms ® field database (van Haaften 1999) that was used by SGS staff during the 2001 field season. Figure 34.1 reflects the database design changes to date, however, some minor modifications of the database design may still be required during data loading to accommodate all existing data.

The SGO database will actually reside in Oracle on MNDM's server, not in Access. MNDM Business Solutions Services are participating in the SGO project to set up the Oracle database. To date, one database migration tool has been successfully tested to migrate the database from Access to Oracle. In future maintenance of the SGO database, data will be converted and loaded using Microsoft Access client computers linked to Oracle by Microsoft ® Open Database Connectivity ® (ODBC).

There will also be an SGO database within the LIO data warehouse which uses Oracle in conjunction with ESRI SDE. The database design for the LIO portion of the project will not be finalized until all existing MRD data have been loaded to MNDM's server, because some database design changes may be needed to accommodate the data.

SGO PROJECT STATUS

As described above, the data analysis was conducted from February 2000 to January 2001. The data model and database for MNDM use were developed and tested in the spring of 2001 and a trial migration to Oracle of the database and test data was done in the summer of 2001.

The next step will be to convert and load all existing digital MRD data to MNDM's database server. Some minor changes to the database design may be required during this process to accommodate all data.

Finally, the LIO warehouse must be modified to accommodate the SGO data and to provide the necessary services. All SGO data must be loaded from MNDM's server to LIO and a database maintenance protocol must be put in place to update MNDM's server and LIO with new data as it's released by the OGS.

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35. Project Unit 00-32. A Resource Evaluation of the Upper Ordovician Shales of Southern Ontario

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INTRODUCTION

The Upper Ordovician Queenston Formation is the primary source of raw material for the brick industry in Ontario. Competing land-uses threaten access to undeveloped shale resources so, in the summer of 2000, the Ontario Geological Survey commenced a regional-scale resource evaluation of the Queenston Formation (Armstrong 2000). Initial results of this study were published in a Miscellaneous Release Data (Armstrong 2001a) and an Open File Report (Armstrong 2001b). In 2001, the scope of the project was expanded to include comparative studies of 2 other Upper Ordovician shale units, the Blue Mountain and Georgian Bay formations.

GEOLOGICAL OVERVIEW

The Upper Ordovician Blue Mountain, Georgian Bay and Queenston formations (Table 35.1) consist of a succession of siliciclastic shales with subordinate limestone and sandstone interbeds. The geology of these formations was recently reviewed by Hamblin (1998, 1999). Other significant publications include those by Liberty (1969), Liberty and Bolton (1971), Russell and Telford (1983), Kerr and Eyles (1991), and Brogly et al. (1998). These 3 formations outcrop (and subcrop beneath Quaternary sediments) in a belt located east of the Niagara Escarpment, extending from Lake Ontario to Georgian Bay (Figure 35.1; Ontario Geological Survey 1991). This outcrop belt is over 100 km wide in the south and less than 10 km wide in the north.

The oldest of these units, the Blue Mountain Formation, consists mainly of grey shale with minor, thin limestone beds. In the southern part of its outcrop belt, the lower part of the formation consists of brownish grey, more organic-rich shale. The Blue Mountain Formation gradationally overlies the organic-rich, black, fissile limestones of the Collingwood Member of the Lindsay Formation. Over most of its outcrop belt the Blue Mountain Formation is poorly exposed and covered by thick Quaternary deposits. Outcrops are known mainly in the Pickering area (i.e., Rouge River valley) and along the shore of Georgian Bay from east of Meaford to west of Collingwood.

The Georgian Bay Formation consists of grey shales with variable amounts of limestone or calcareous sandstone interbeds. Limestone and sandstone interbeds generally increase in abundance upwards through the formation (Kerr and Eyles 1991; Byerley and Coniglio 1991) and some workers (e.g., Liberty 1969) have subdivided the Georgian Bay Formation into 2 informal members: a lower shalier member and an upper member with more limestone or sandstone beds. The basal contact of the Georgian Bay Formation with the Blue Mountain Formation is gradational and commonly placed at the base of the first significant (i.e., greater than 5 cm thick) limestone bed (e.g., Johnson et al. 1992). Georgian Bay Formation exposures are found in river and creek valleys in Toronto and Mississauga, in large shoreline outcrops on Georgian Bay in the vicinity of Meaford and along creeks flowing into Georgian Bay.

The Queenston Formation is characterised by red shales, however, it does contain thin, locally significant, interbeds of limestone, siltstone, sandstone and green shale. Fossiliferous limestone beds occur in the middle of the formation in the northern part of the outcrop belt. In the southern part of its outcrop belt, the middle part of the formation is generally more calcareous than the upper and lower parts (Armstrong 2001b). The Queenston Formation is also found in a fault-bounded erosional outlier in the vicinity of Russell, south of Ottawa (Williams and Telford 1986). This outlier also contains, though poorly exposed, strata equivalent to the Georgian Bay and Blue Mountain formations (Williams 1991).

2001 FIELD WORK

The methodology of this year's field work is essentially the same as that used in 2000 (*see* Armstrong 2000 and 2001b). Major outcrops and available cores were examined and areas of thin drift (less than 8 m) over the shale units were explored for available outcrops. Thin drift areas were identified from previously published sources (e.g., Golders Associates Ltd. and Rowell 1996; Vos 1975).

Initially, field work focussed on the investigation of significant Queenston Formation outcrops and cores that were not examined during last year's field work, including an outlier of this formation, located in eastern Ontario. The outcrops studied in 2001 were mainly located in the Mansfield and Creemore areas of southern Ontario.

Three Queenston Formation quarries were studied in 2001: 1) the inactive Niagara (formerly Burnstein) Quarry, located near St. Davids on the Niagara Peninsula and owned by Canada Brick; 2) the presently inactive, former Hamilton Brick Ltd. Quarry, now the site of Century Brick's plant; and 3) the Russell Quarry, located just north of the village of Russell, in eastern Ontario. The Russell Quarry supplies raw material to Canada Brick's plant in Ottawa.

The Queenston Formation was also studied in 2 cores: 1) the "Russell well", drilled in lot 24 concession 2, Russell Township in 1969 by the Geological Survey of Canada (Williams 1991); and 2) a core drilled by the OGS in 1980 at the inactive Duntroon Quarry (south of Collingwood). The Russell core is stored at the Geological Survey of Canada's core storage repository in Ottawa. The Duntroon core is stored at the Oil, Gas and Salt Resource Library in London, Ontario. Chip samples of the Duntroon core were obtained for geochemical analysis for this study.

Investigation of the Georgian Bay Formation mainly focussed on large, well-documented (e.g., Kerr and Eyles 1991; Liberty 1969) outcrops in the Toronto and Meaford areas, as well as available exposures in the vicinity of thin drift areas. Over most of its outcrop belt, this unit is covered by thick Quaternary deposits. Areas of thin drift (outside of heavily urbanised areas) occur northeast of Brampton, between Alliston and Rosemont, and along Georgian Bay between Collingwood and Owen Sound.

The Blue Mountain Formation is poorly exposed due to its shaly nature and to an extensive cover of Quaternary deposits. One outcrop on the Rouge River, west of Pickering, was examined and sampled for geochemical analysis. Two outcrops in the vicinity of Christie Beach, southeast of Meaford, were also investigated and sampled.

CONTINUING WORK

On-going investigations include examination of these formations in existing drill cores and in cores to be obtained in a drill program planned for October 2001. Existing cores include those drilled by the Ontario Geological Survey near Wiarton, Corbetton, Banks (southwest of Collingwood) and Milton (Johnson et al. 1983, 1985; Johnson 1983). Intervals of the Blue Mountain, Georgian Bay and Queenston formations in these cores will be logged and sampled for geochemical analysis. These data will provide important regional and stratigraphic context for this study.

A drilling program in support of the expanded mandate of this project is planned for October 2001. Holes will be located so as to evaluate areas of thin drift over the Georgian Bay or Blue Mountain formations, or to provide regional or sub-regional reference sections for these formations.

Outcrop and core samples of the shale units obtained from 2001 field investigations have been submitted to the Ontario Geoscience Laboratories for major element, carbon and sulphur analysis. Core samples of the Queenston Formation from the 2000 drilling program (Armstrong 2000, 2001b) were submitted for ceramic testing to the National Brick Research Center at Clemson University in Anderson, South Carolina.

ACKNOWLEDGEMENTS

The technical assistance and advice of Tony Hamblin (GSC-Calgary) was most appreciated. The on-going co-operation of the management and staff of Canada Brick Ltd., Century Brick, and Brampton Brick Ltd. is also much appreciated. Access to the Canada Forces Training Centre Meaford was kindly allowed by Captain Mark Toma and assistance there provided by Warrant Officer Fred Myre. Field assistance was most capably provided by Pascale Sergerie.

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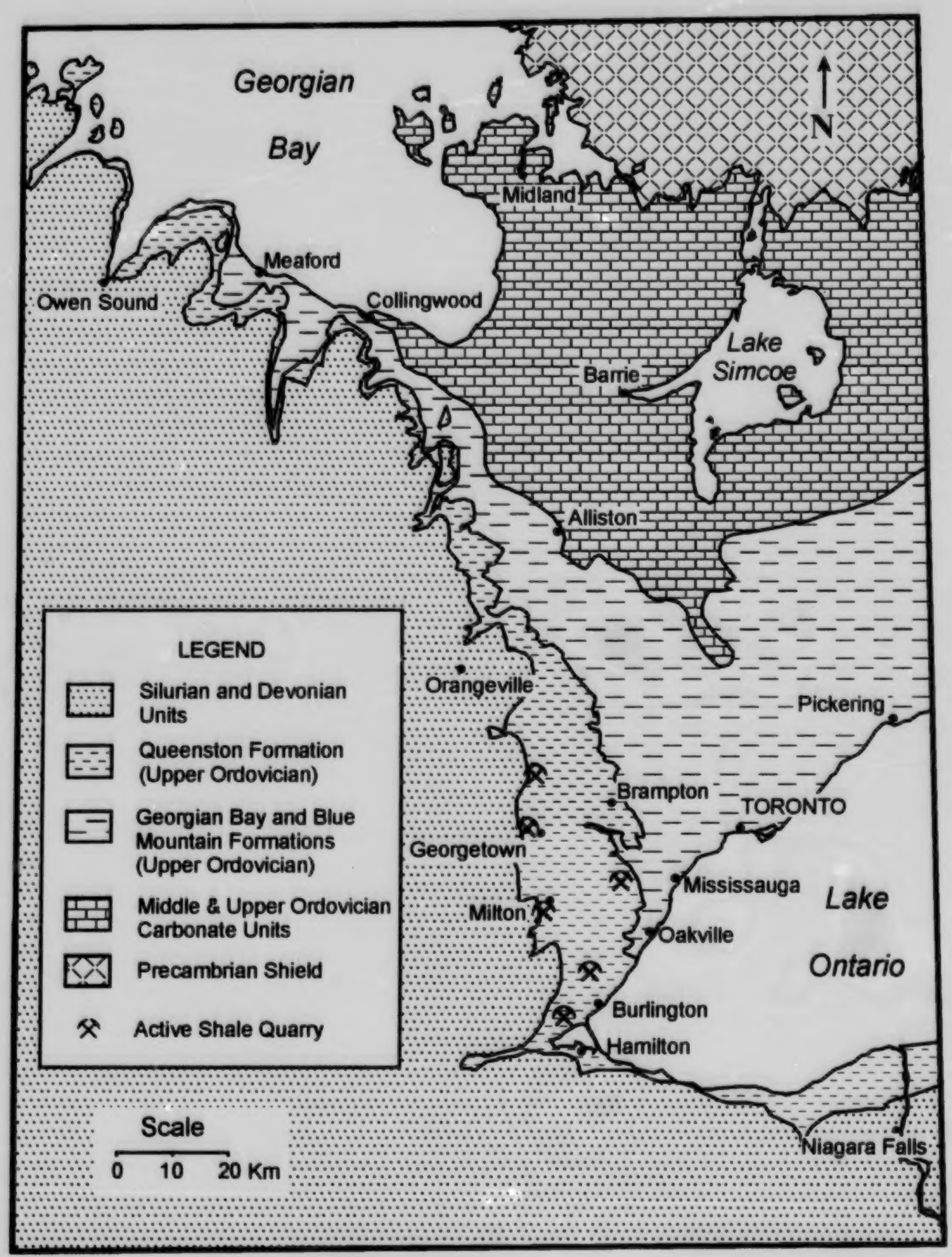
Georgian Bay
N
Midland
Meaford
Owen Sound
Collingwood
Lake Simcoe
Barrie
Alliston
LEGEND
Silurian and Devonian Units
Queenston Formation (Upper Ordovician)
Georgian Bay and Blue Mountain Formations (Upper Ordovician)
Middle & Upper Ordovician Carbonate Units
Precambrian Shield
Active Shale Quarry
Orangeville
Pickering
Brampton
TORONTO
Georgetown
Mississauga
Lake Ontario
Milton
Oakville
Burlington
Hamilton
Scale
0 10 20 Km
Niagara Falls

Figure 35.1. Generalized bedrock geology map of south-central Ontario, showing the distribution of the Queenston Formation and the Georgian Bay and Blue Mountain formations and the locations of active shale quarries (geology after Ontario Geological Survey 1991).

Table 35.1. Upper Ordovician and Lower Silurian stratigraphic chart for the Niagara Escarpment area, southern Ontario (from Johnson et al. 1992). Note: "Fm" = Formation; "Mb" = Member.

Age	Geographic Areas		
	Niagara Peninsula area	Alliston-Collingwood area	Owen Sound – Meaford area
Lower Silurian	Whirlpool Fm	Manitoulin Fm	Manitoulin Fm
		Whirlpool Fm	
Upper Ordovician	Queenston Fm	Queenston Fm	Queenston Fm
	Georgian Bay Fm	Georgian Bay Fm	Georgian Bay Fm
	Blue Mountain Fm	Blue Mountain Fm	Blue Mountain Fm
	Collingwood Mb (Lindsay Fm)	Collingwood Mb (Lindsay Fm)	Collingwood Mb (Lindsay Fm)

Geoscience Program Initiatives

36. Operation Treasure Hunt – 2001 Overview

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[3]Land Cluster Business Solutions Section
[4]Information and Marketing Services Section
[5]Paterson, Grant & Watson Limited

INTRODUCTION

Announced by the Ministry of Northern Development and Mines in April 1999, Operation Treasure Hunt (OTH) is a three-year, $29 million Government of Ontario initiative to stimulate the minerals industry. OTH will increase Ontario's attractiveness to prospecting and mineral exploration investment by applying state-of-the-art technology and methods to uncover exciting new mineral exploration targets. The OTH program terminates March 31, 2002.

The Ontario Geological Survey continued to work closely with the OGS Advisory Board (OGSAB) and Technical Committee (TC) to identify the needs and priorities of the minerals industry. The Technical Committee of the OGSAB identified to the OGS geographic areas of interest and commodities of interest.

OPERATION TREASURE HUNT GEOSCIENCE PROGRAM

The 2000 to 2001 OTH geoscience program is designed to meet the needs and priorities of the minerals industry:

a) Airborne geophysical survey program (Reford et al., this volume)
   - flying of new airborne geophysical surveys over the Fort Hope greenstone belt
   - acquisition of existing proprietary airborne geophysical surveys
   - continued development of an atlas and database to illustrate the location, ownership, and technical specifications of some airborne geophysical surveys over Ontario

b) Physical rock properties project (Deschamps and Morris, this volume)

c) 1:250 000 scale bedrock geology map compilation (Johns, this volume)

d) Compilation and understanding of platinum group element mineralization and mafic to ultramafic intrusions across Ontario (Vaillancourt et al., this volume) in partnership with the Geological Survey of Canada

e) Compilation and understanding of fertile peraluminous granites and related rare-element pegmatite mineralization in Ontario (Breaks, Selway and Tindle, this volume)

f) Thick overburden geochemistry methods (Hamilton and Cranston, this volume)
   - develop surficial exploration methodology using partial extractions (i.e., selective leaches)

  - develop better technique for measures electrochemical properties (i.e., redox) in overburden

g) Lake sediment surveys (Dyer and Roy, this volume)
  - collection of lake sediment and/or water samples in areas of high and unknown mineral potential

h) Indicator minerals (Crabtree and Dyer, this volume)
  - stream and river sampling in areas favourable for kimberlite intrusions
  - purchase of propriety data from the private sector

i) Surficial Geoscience Observations Database
  - Development of data model and population of database

j) CLAIMaps Project
  - a Mining Lands application, providing Internet access to land status within Ontario

k) Data management, claim maps web serving application and product dissemination

The highlights of each OTH project are described in more detail in the following section.

OPERATION TREASURE HUNT 2000 TO 2001 PROGRAM HIGHLIGHTS

Between fall 2000 and fall 2001, OTH program highlights include

a) Airborne geophysical survey: flew approximately 169 000 line kilometres of new airborne geophysical surveys over areas of high mineral potential (Reford et al., this volume): 33 875 line kilometres of airborne magnetic and time-domain electromagnetic survey over the Dryden–Ignace–Stormy Lake area ("the Stormy Lake survey") (November 2000 to March 2001); and 135 460 line kilometres of magnetic, magnetic–gamma-ray spectrometric, and magnetic and time-domain electromagnetic survey over the Fort Hope greenstone belt ("the Fort Hope survey") (June 2001 to March 2002).

b) Purchase of proprietary airborne geophysical data: purchased about 122 000 line kilometres of existing, technically current, airborne geophysical magnetic and magnetic–electromagnetic data from the private sector at a discount of about 80% off current market rates to fly the same area (Reford et al., this volume).

c) Airborne geophysical survey atlas: posting on the Internet of an Atlas to illustrate the location of some airborne geophysical surveys in MNDM assessment files and all OGS and Geological Survey of Canada airborne geophysical surveys (Rudd, this volume).

d) Physical rock properties: continuation of the project to measure and apply physical rock properties for samples collected from the Abitibi greenstone belt (Deschamps and Morris, this volume).

e) Publication of 2 Precambrian bedrock 1:250 000 scale compilation sheets (Johns, this volume), Schreiber (Map 2665) and White River (Map 2666), that augment the previous release of Quetico (Map 2663) and Thunder Bay (Map 2664).

f) Initiation of a provincial-scale platinum group element mineralization and mafic to ultramafic intrusion inventory project in collaboration with the Mineral Exploration Research Centre (MERC) Laurentian University and the Mineral Resources Division of the Geological Survey of Canada (Vaillancourt et al., this volume).

g) Initiation of a provincial-scale study and compilation of fertile peraluminous granites and related rare-element pegmatite mineralization (Breaks, Selway and Tindle, this volume).

h) Publication of the CAMIRO whole-rock lithogeochemical data set: "Whole Rock Lithogeochemical Data of Prospective versus Barren Volcanic Belts for Volcanogenic Massive Sulphide (VMS) Deposits, Superior Province, Ontario: Operation Treasure Hunt" (Miscellaneous Release—Data 85).

i) Investigation of the thick overburden exploration techniques has yielded the following: evidence of geochemical processes occurring between bedrock and ground surface; methodologies capable of determining the redox (i.e., electrochemical) character of overburden materials and negatively charged areas exist over mineralization; and sampling protocols that yield greatly enhanced results when using partial digestion geochemistry for mineral exploration (Hamilton and Cranston, this volume).

j) Lake sediment surveys: moderate- to high-density surveys were conducted in the following areas: Lac des Iles–Black Sturgeon, 2237 samples covering 9900 km^2; Sudbury–River Valley, 1415 samples covering 4850 km^2; and Temagami, 2413 samples covering 8200 km^2. In addition to lake sediment samples, water samples were collected in the Sudbury and Temagami regions (Dyer and Roy, this volume).

k) Data release of lake sediment geochemical results in Open File Reports and digital data releases for the 6 areas, including 5 areas in which archived samples were analyzed for palladium, platinum and gold.

l) Indicator mineral surveys: undertaken in the Sault Ste. Marie–Espanola area (~750 samples) and in that part of the James Bay Lowland bounded by the catchment region of the Ekwan River in the north and the Albany River in the south (~1300 samples).

m) Release of 4 indicator mineral reports covering the Kapuskasing Structural Zone (Crabtree and Dyer, this volume).

n) Initial population of the Surficial Geochemical Observations Database (SGOD) and review by a stakeholder user group.

o) Completion of industrial mineral investigations: geotechnical and economic study of high value bedrock aggregate products, north shore of Lake Superior; and an inventory and examination of white mica deposits in eastern Ontario.

p) The CLAIMaps system is a Mining Lands application, which provides Internet access to land status within Ontario, to exploration companies, prospectors, and the general public 24/7/365. Clients can view land tenure, access information about mining claims and download high-quality maps at no cost. The CLAIMaps project will further enhance the Internet tools for clients, as well as pave the way for the integration of this Mining Lands information with geospatial and other valuable data within Government.

q) Release of 25 hardcopy 1:20 000 scale maps, 198 hardcopy full colour 1:50 000 scale maps, and approximately 30 CD-ROMs and 7 DVDs containing over 70 Gb of airborne geophysical data.

PROGRAM PERFORMANCE

To address the impact of the OTH and the core geoscience program, staking patterns within OTH project areas are monitored (Churchill, Fyon and Baker, this volume). The number of active claims in several of the OTH project areas increase by three- to four-fold during the OTH survey and following the release of the survey products (Churchill, Fyon, and Baker, this volume). A customer survey will measure the economic impact of the OTH projects. While the short-term impacts are encouraging, the true value of geoscience is realized over many years.

37. Project Unit 99-302. Operation Treasure Hunt: Airborne Geophysical Projects

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INTRODUCTION

Between April 1, 2000 and March 31, 2001, the Operation Treasure Hunt (OTH) airborne geophysical program consisted of three projects:

1. fly new airborne magnetic and electromagnetic (EM) surveys
2. purchase from the private sector existing airborne geophysical surveys that met technical criteria and geographic priorities
3. develop an atlas to illustrate the geographic location of some legacy airborne geophysical surveys covering Ontario

In summer 2001, the third year geophysical component of OTH consisted of new airborne magnetic, electromagnetic and gamma-ray spectrometric surveys.

To manage these projects, the Ontario Geological Survey (OGS) retained Stephen Reford (Paterson, Grant & Watson Limited) as project manager and OTH Geophysicist.

NEW AIRBORNE GEOPHYSICAL SURVEY PROJECT

Survey Areas and Survey Selection Considerations

Between November 2000 and fall 2001, approximately 169 000 line kilometres of new airborne surveys were flown over areas of high mineral potential (Figure 37.1). The new airborne geophysical surveys include 33 875 line kilometres over the Dryden–Ignace–Stormy Lake area (the "Stormy Lake survey") (November 2000 to March 2001) and 135 460 line kilometres over the Fort Hope greenstone belt (the "Fort Hope survey") (June 2001 to March 2002). These surveys supplement approximately 105 000 line kilometres of new surveys that were flown during the first year of OTH (Reford et al. 2000).

Survey areas were selected by considering

- advice from the OGS Advisory Board
- quantity and quality of existing OGS airborne data
- review of proprietary airborne data available from the private sector
- known or interpreted extent of geological units and mineral targets of interest

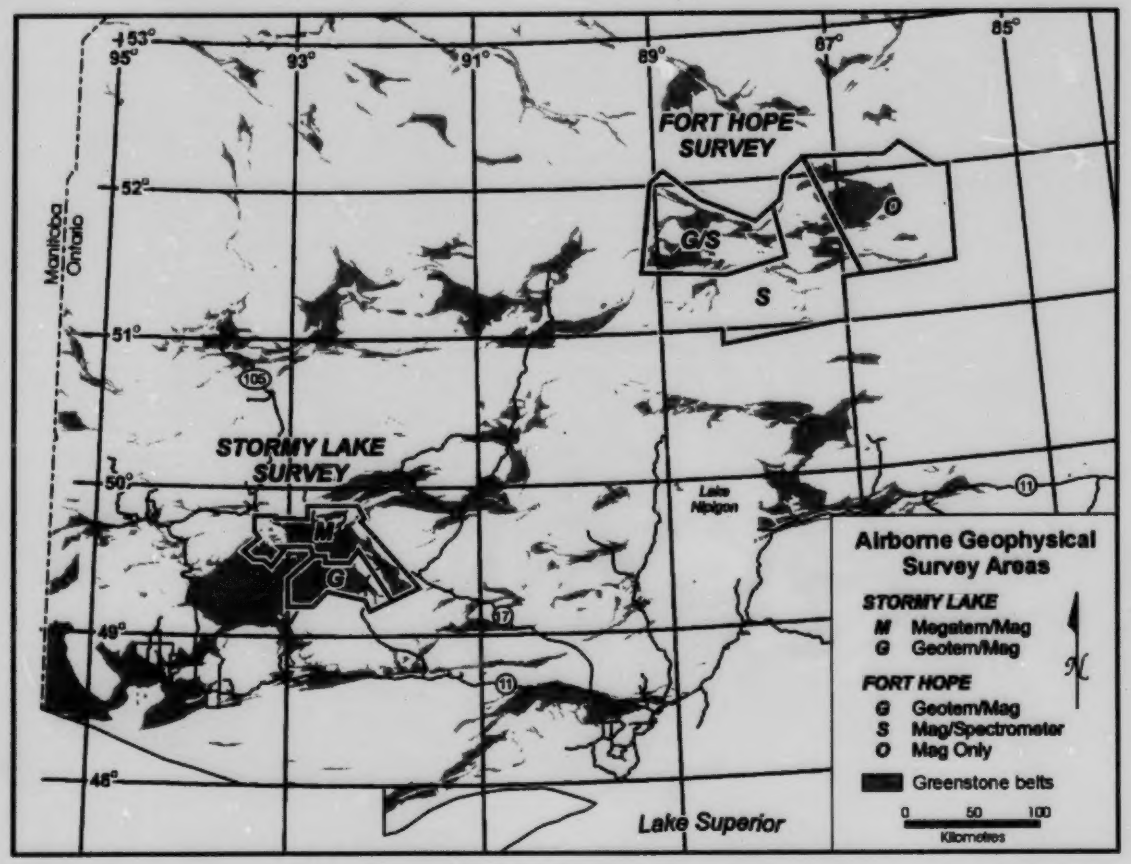
53°
95°
93°
91°
89°
87°
85°
FORT HOPE SURVEY
G/S
O
S
52°
51°
50°
49°
48°
Manitoba
Ontario
105
STORMY LAKE SURVEY
M
G
17
11
Lake Nipigon
Lake Superior
Airborne Geophysical Survey Areas
STORMY LAKE
M Megatem/Mag
G Geotem/Mag
FORT HOPE
G Geotem/Mag
S Mag/Spectrometer
O Mag Only
Greenstone belts
0 50 100
Kilometres
N

Figure 37.1. Operation Treasure Hunt Airborne Geophysical survey areas (2001 to 2002). Solid black areas represent areas of supracrustal rocks dominated by metavolcanic rocks.

Time-domain (TDEM) electromagnetic survey systems were employed for the Stormy Lake and a portion of the Fort Hope survey (Table 37.1), as they were judged most suitable for penetration beneath thick and/or conductive overburden. Gamma-ray spectrometer data were acquired for the first time in OTH on the Fort Hope survey—made feasible due to the survey taking place during the summer, when snow cover would not limit its effectiveness. Magnetic survey data were collected over all of the areas flown.

The Stormy Lake survey blocks (*see* Figure 37.1) are located in a known exploration area and partially overlap existing OGS surveys. Magnetic–TDEM surveys were flown over these areas because the latest generation of TDEM technology, with its increased resolution and depth penetration, provided new insight into the geology of the region. The Fort Hope survey blocks (*see* Figure 37.1) are located in relatively virgin exploration areas, over a granite-greenstone terrane that extends east beneath the Palaeozoic sediments of the James Bay Lowlands. Magnetic–gamma-ray spectrometric surveys cover the western portion of the Fort Hope region, and the magnetic only survey covers the eastern portion. The gamma-ray spectrometric method was not utilized in the latter area due to the prevalence of swamp that limits its effectiveness. To the west, the gamma-ray spectrometric data will provide additional insight into the exposed bedrock and Quaternary cover, complementing the responses from the magnetic data. The northwest portion of the Fort Hope survey area was assessed as having the greatest potential for detecting conductive mineralization by the TDEM method.

Table 37.1. Summary of new airborne geophysical surveys.

Survey Name	Line Kilometres	Geophysical Systems
Stormy Lake North	21 869	Megatem – a high energy, pulse-type, fixed-wing magnetic–TDEM system that acquires X, Y and Z-components of the secondary TDEM field (90 Hz base frequency)
Stormy Lake South	12 005	Geotem III – a pulse-type, fixed-wing magnetic–TDEM system that acquires X, Y and Z-components of the secondary TDEM field (90 Hz base frequency)
Fort Hope Northwest	31 429	Geotem III – a pulse-type, fixed-wing magnetic–TDEM system that acquires X, Y and Z-components of the secondary TDEM field (90 Hz base frequency)
Fort Hope West	24 502	Terraquest – a fixed-wing magnetic–gamma-ray spectrometric system
Fort Hope Central	44 738	Fugro Sial – a fixed-wing magnetic–gamma-ray spectrometric system
Fort Hope East	34 789	Fugro Sial – a fixed-wing magnetic system

Survey Specifications

The Stormy Lake and Fort Hope electromagnetic–magnetic airborne survey systems were flown under contract by Fugro Airborne Surveys Corporation. Each airborne system acquired both the electromagnetic and magnetic data using towed birds, providing superior resolution due to their closer proximity to the ground. The surveys were flown at 200 m line spacing, with 1500 m control line spacing. The strike of local bedrock geology determined the flight line direction. The Stormy Lake survey area was divided into sub-blocks to accommodate local changes to geological strike. The Geotem III system was employed for the Fort Hope EM survey and the southern portion of the Stormy Lake survey. The Megatem system was employed for the northern portion of the Stormy Lake survey, where thick and conductive overburden warranted the use of its higher EM transmitter power.

The Fort Hope magnetic–gamma-ray spectrometric survey systems were flown under contract by Terraquest Ltd. and Fugro Sial Airborne Surveys Inc., and the magnetic-only survey system by Fugro Sial Airborne Surveys Inc. The magnetometers were mounted on the tail of the aircraft, and the gamma-ray spectrometers were installed inside. The surveys were flown at 250 m line spacing, with 2000 m control line spacing. The prevalent strike of local bedrock geology determined a single flight line direction (345°) for the entire Fort Hope survey area.

Airborne Geophysical Survey Products

Both digital and map products in publication-ready form are available for the Stormy Lake airborne geophysical survey and will be available for the Fort Hope airborne geophysical survey. The digital products include

- profile database of the raw, intermediate and final data channels
- archive of the "streamed" halfwave TDEM data
- grids of the total magnetic intensity, its second vertical derivative, TDEM decay constant (tau), TDEM apparent conductance, radioelements (potassium (K), uranium (U), thorium (Th), U/K ratio, Th/K ratio, U/Th ratio and total air-absorbed dose rate) and digital elevation model

- Keating coefficients used to identify magnetic anomalies that may correspond to circular kimberlite bodies
- electromagnetic anomaly database including model parameters
- 1:20 000 and 1:50 000 scale maps of certain grid products
- GIS-ready image and vector files of the geophysical data
- survey reports

The hard-copy maps consist of total magnetic intensity contours with flight path and EM anomalies at 1:20 000 scale for the TDEM surveys, and total magnetic intensity contours with flight path and Keating coefficients at 1:50 000 scale for the magnetic–gamma-ray spectrometric and magnetic only surveys. Additional 1:50 000 scale magnetic, electromagnetic and gamma-ray spectrometric map products will be prepared for all areas for "print-on-demand" requests.

OTH Airborne Geophysical Test Site

The Reid–Mahaffy Airborne Geophysical Test Site (Ontario Geological Survey 2000), established prior to the airborne geophysical surveys flown in the first year of OTH, was once again utilized to evaluate the EM systems prior to each of the Stormy Lake and Fort Hope airborne EM surveys. Consequently, the Geotem III and Megatem systems flew the test site survey prior to mobilizing to Stormy Lake, and the Geotem III system flew it again prior to mobilizing to Fort Hope. The Megatem system had not previously flown the test survey for OTH. The transmitter configuration of the Geotem III system was changed from what was used during the first year of OTH. The results of the test range are aimed at the expert geophysicist. Therefore, the test range results are available only in digital format.

The site has been flown by additional electromagnetic systems outside the auspices of OTH. Some of the OTH and other results from the site have been published and analyzed (e.g., Irvine, Godbout and Witherly 2000; Boyko, Paterson and Kwan 2001; Bishop and MacNae 2001).

PURCHASE OF EXISTING PROPRIETARY AIRBORNE GEOPHYSICAL SURVEY DATA

Through an open tender process, existing proprietary airborne survey data were sought from industry to complement the existing and new government coverage. The survey data were valued using geographic, technical and quality criteria. Approximately 113 000 line kilometres of magnetic and magnetic–electromagnetic surveys were purchased during the first year of OTH (Reford et al. 2000). The process was repeated during the second year of OTH, and an additional 123 000 line kilometres of magnetic and magnetic–electromagnetic surveys were purchased (Table 37.2).

All data sets are reformatted and documented prior to release. Some of the purchased proprietary data require additional processing (e.g., levelling of magnetic data) and/or are supplemented by files obtained from the original survey contractor (e.g., EM anomaly databases). The Keating coefficients are computed for each survey. In addition to the digital data, map products are prepared to serve the full client base of the OGS, although the purchased surveys (60 000 series maps) lack planimetric bases.

The purchased data sets will be released between December 2001 and December 2002.

Table 37.2. Proprietary airborne geophysical survey data purchased under Operation Treasure Hunt (fiscal year 2000 to 2001).

Company Name	Survey Name	Survey Type	Line Kilometres
Falconbridge Limited	Robb–Jamieson	TDEM, mag	1973
Falconbridge Limited + Explorers Alliance Corporation	Turnbull–Godfrey	TDEM, mag	1058
WMC International Ltd.	River Valley West	FDEM, VLF, mag	1892
Noranda Inc.	Troutlake River	TDEM, mag	1465
Noranda Inc.	Pakwash Lake	TDEM, mag	642
Noranda Inc.	Melchett Lake	TDEM, mag	365
Leader Mining International Inc.	Natogami Lake	FDEM, VLF, mag	1067
Alcanex	Coral Rapids	Mag	4245
Alcanex	Kesagami Lake	Mag	1607
Spider Resources Inc.	Attawapiskat West	Mag	36 156
Spider Resources Inc.	Attawapiskat East	Mag	62 358
Navigator Exploration Corp.	Kapiskau River East	Mag	10 026

Explanation of abbreviations: FDEM, Frequency domain electromagnetic survey; TDEM, Time domain electromagnetic survey; VLF, Very low frequency electromagnetic survey; Mag, magnetic survey

AIRBORNE GEOPHYSICAL SURVEY ATLAS

An atlas of the many significant airborne geophysical surveys flown over Ontario, that are available in the public domain, was upgraded. The surveys incorporated in the atlas include

- the historical magnetic–electromagnetic surveys flown by the OGS between 1975 and 1992
- the new OTH magnetic–electromagnetic, magnetic–gamma-ray spectrometric and magnetic only surveys flown in 1999 to 2001
- the proprietary airborne surveys purchased from the private sector for OTH in 2000 to 2001
- the proprietary airborne surveys submitted for evaluation, but not purchased by OTH
- the historical and recent magnetic surveys (some with radiometric and/or electromagnetic data) flown by the Geological Survey of Canada
- selected surveys documented in the MNDM assessment records

The airborne geophysical survey atlas will be released for access over the web: http://www.gov.on.ca/MNDM/MINES/oth

COMMUNITY OUTREACH

The Stormy Lake and Fort Hope airborne geophysical surveys have involved an extensive consultation process with First Nation communities located within the survey areas, to facilitate planning and logistics, and ensure that treaty rights were not infringed. An educational component included a one-day open house at the Dryden airport for the Eagle Lake and Wabigoon First Nation communities and a half-day open house at the Fort Hope airport for the Eabametoong First Nation community. Ontario

Geological Survey staff and survey contractor personnel presented an overview of mineral exploration and geology, and specifics of the airborne survey systems, including tours of the aircraft.

The results of the airborne geophysical component of OTH have been presented at various mineral exploration symposia throughout Ontario (Toronto, Thunder Bay, Sudbury, Kirkland Lake), and at technical conferences in Canada (Reford and Fyon 2000a), the United States (Reford and Fyon 2000b) and Australia (Reford, Rudd and Churchill 2001). Survey design and planning has involved co-operation with geophysicists from the Geological Survey of Canada, United States Geological Survey, Geological Survey of New South Wales and Northern Territory Geological Survey.

The OTH geoscience program has triggered staking and follow-up exploration. An overview of the economic impact of the OTH program and related OGS core geoscience projects is discussed by Churchill et al. (this volume).

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38. Project Unit 01-303. Potential for Platinum Group Elements Mineralization in Mafic–Ultramafic Intrusions in Ontario

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INTRODUCTION

This report is a summary of the Operation Treasure Hunt project on the study of platinum group elements (PGE) potential in "mafic–ultramafic" intrusions[4] in Ontario, which was initiated in January 2001. This initiative represents a collaboration between the Ontario Geological Survey (OGS), the Mineral Exploration Research Centre (MERC) of Laurentian University and the Geological Survey of Canada. It will result in the development of a comprehensive database outlining critical geological information on mafic–ultramafic intrusions and PGE mineralization in Ontario, and new lithogeochemical data for mafic–ultramafic intrusions across the province. This database will provide a key framework to increase our understanding of PGE mineralization in mafic–ultramafic intrusions of Ontario.

The present shortfall in the world's supply of palladium and, to a lesser degree, platinum has resulted in significant increases in the price of these metals to record levels of US$1090 per ounce and US$640 per ounce, respectively, in January 2001. Thus, these metals offer important exploration targets for both junior and senior exploration companies. Ontario is placed in an excellent position to take advantage of this current high level of exploration interest as the province has a large number of mafic–ultramafic intrusions, which are common host rocks for PGE mineralization. Although the genesis of palladium and platinum deposits has been extensively studied (e.g., Campbell, Naldrett and Barnes 1983; Campbell and Barnes 1984; Ballhaus and Stumpfl 1986; Brügmann, Naldrett and Macdonald 1989; Hoatson and Keays 1989; Lambert et al. 1994; Naldrett 1997; Naldrett, Brügmann and Wilson 1990; Cawthorn 1999), much of the research interest has focussed predominantly on reef-style mineralization that is restricted to layered mafic–ultramafic intrusions (Hoatson and Keays 1989; Lambert et al. 1994; Cawthorn 1999). Thus, an important opportunity exists to document other styles of PGE mineralization, including

1. contact-style mineralization (e.g., River Valley: Hrominchuk 2000; East Bull Lake: Peck et al. 2000)
2. hydrothermal PGE mineralization (e.g., Lac des Iles: Brügmann, Naldrett and Macdonald 1989)
3. structurally controlled hydrothermal mineralization (e.g., Rathbun Lake, Wanapitei Complex: Rowell and Edgar 1986)
4. mineralization in sills or "feeder conduits" (Nipissing gabbro, Logan sills, Nipigon plate intrusions)
5. stratabound mineralization (e.g., Platinova Reef, Skaergaard intrusion, Greenland: Bird et al. 1991; Andersen et al. 1998)

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[4] As used in this paper, the term "mafic–ultramafic" refers to intrusions composed of mafic rocks only, ultramafic rocks only, or a combination of mafic and ultramafic rocks.

A significant amount of research is still required to determine the relationship between PGE mineralization potential and the petrogenesis of the host intrusions and subsequent geological processes. Such studies help to identify key factors including

- recognition of favourable tectonic settings (e.g., rifts, back arcs) and favoured mantle source regions (e.g., metasomatized refractory mantle: Hamlyn and Keays 1986)
- magmas types and subsequent processes, such as
  - interaction with crustal material (e.g., sulphur-bearing sediments: Naldrett et al. 1992)
  - the role of late stage volatiles (e.g., Boudreau and Meurer 1994)
  - post-emplacement processes such as serpentinization (Thalhammer and Stumpfl 1988)
  - metamorphism and deformation (Rowell and Edgar 1986)

all or some of which may cause redistribution of PGE mineralization. An understanding of these processes aids in delineation of prospective intrusions and geologic regions that is essential for successful exploration programs.

SELECTION CRITERIA FOR MAFIC–ULTRAMAFIC INTRUSIONS

The main focus of this project involved an extensive, province-wide campaign to sample a significant number of prospective mafic–ultramafic intrusions in Ontario. An initial list of 180 intrusions was assembled by E.J. Debicki (Ontario Geological Survey, unpublished data, 2000) based on recommendations of geoscientists in the OGS Precambrian Geoscience Section, the OGS Resident Geologist Program and geologists from several companies that are actively exploring for PGE in Ontario. This list was reduced to approximately 70 intrusions utilizing the following selection criteria:

1. include a representative suite of intrusions from the 3 geological provinces in Ontario (Grenville, Southern and Superior) as all three have excellent or proven potential for PGE mineralization
2. select a representative number of intrusions in a variety of tectonic settings
3. select different types of intrusions representing various magma types, compositions, rock types and morphologies
4. select intrusions that host different styles of PGE mineralization, including barren intrusions for comparison

Where selection had to be made between similar intrusions in a specific area, priority was given to the candidates that had the best outcrop exposure and easiest access. For example, an intrusion that is accessible by a combination of truck, all-terrain vehicle (ATV) and boat would be picked over an intrusion that is only accessible by plane or helicopter. For areas where there were no other possibilities, planes were used to access the intrusions.

The most important selection criteria initially was geographic coverage, as this also broadly covers a range of tectonic settings, which, in turn, controls the types of intrusions observed. For this reason, all candidate intrusions were grouped according to Resident Geologist districts. These include Red Lake, Kenora, Thunder Bay South, Thunder Bay North, Sault Ste. Marie, Timmins, Sudbury, Kirkland Lake and Southeastern Ontario (there were no candidate intrusions in the Southwestern Ontario district). Then, all districts were assessed separately using the above criteria.

Favourable weather conditions, easy access and many other positive factors, made field investigation possible in less time than estimated. This allowed for the addition of intrusions that were originally rejected. The selection was done using the same criteria previously described. The list of candidates also evolved throughout the field season. Some intrusions were dismissed, typically due to difficult access (restricted by land owners, gated roads, washed-out roads, etc.), and other intrusions were added based on additional information or samples provided by the Ontario Geological Survey (Precambrian Geoscience Section and Resident Geologist Program), companies, prospectors and academics. A total of 98 intrusions were ultimately investigated, the locations of which are indicated in Figure 38.1. Intrusion names are listed in Table 38.1, including brief information on the dominant rock types present and if PGE mineralization has previously been recognized.

FIELD INVESTIGATION

Field work was undertaken by 4 two-person crews sampling from mid-May to the beginning of September. The majority of the sampling was conducted at surface, supplemented with diamond-drill core samples kindly provided by companies, particularly in areas where outcrop was poor. Sampling was undertaken with the strategy of

1. obtaining a good stratigraphic section through an intrusion, where appropriate (this applied to intrusions that have well-defined layering such as the Centre Hill Complex in the Abitibi greenstone belt);
2. obtaining samples from each of the known rock types within an intrusion (this particularly applies to heterogeneous intrusions with a number of phases, for example, the Entwine Lake intrusion in the Wabigoon Subprovince);
3. focussing on phases within an intrusion that are known to be associated with PGE mineralization in other mineralized hosts, for example, areas of repeated magmatic stratigraphy, mafic–ultramafic contacts, varitextured and pegmatoidal zones, areas of high degrees of alteration.

The number of samples ranged typically from 10 to 30 per intrusion depending on access, quality of outcrop, size of the intrusion and complexity of the intrusion.

Approximately 1300 samples from the 98 intrusions were submitted for geochemical analysis and thin sections. Table 38.2 lists the elements that were selected for analysis, including the reasoning for the selection.

SAMPLE PREPARATION

A larger volume of sample was prepared and special care was taken to minimize contamination, with a plan of reusing the sample powder in the future for further geochemical analysis (various trace elements by ICP–MS, extended PGE by nickel fire assay, etc.). All samples were first cut into regular blocks with a table saw. All cut surfaces were then abraded on a clean lapping wheel to remove the saw marks and all other potential contaminants. Finally, the samples were thoroughly rinsed with water purified by reverse osmosis. All geochemical analyses were undertaken at the Geoscience Laboratories, Ontario Geoservices Centre, Sudbury.

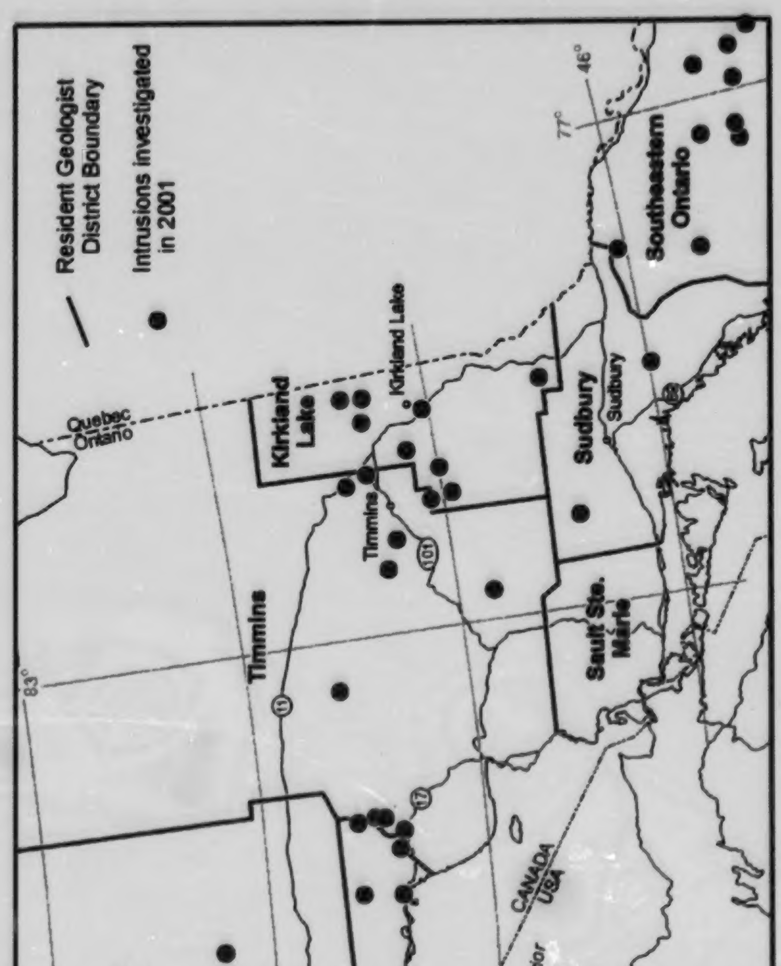
Resident Geologist District Boundary
Intrusions investigated in 2001
Quebec
Ontario
Kirkland Lake
Kirkland Lake
Timmins
Timmins
Sudbury
Sudbury
Southeastern Ontario
Sault Ste. Marie
Thunder Bay North
Thunder Bay South
Thunder Bay
Kenora
Kenora
Red Lake
Manitoba
Ontario
Lake Superior
CANADA
USA
11
17
101
69
95°
52°
50°
48°
89°
83°
77°
46°
200 kilometres

Figure 38.1. Location of intrusions investigated in 2001.

Table 38.1. List of intrusions investigated in 2001. Note that some intrusions may be added to the final list in the report.

Intrusion Name	Area	Geologic (Sub)Province	Composition	Known PGE	Sulphides Observed	Resident Geologist District
Abitibi Canyon – Pinard intrusion	Kapuskasing	Quetico	Mafic > Ultramafic	N	N	Timmins
Abiwin Lake	Mine Center–Thunder Bay	Nipigon Plate	Mafic > Ultramafic	Y	Y	Thunder Bay South
Bad Vermillion	Mine Center	Wabigoon	Mafic	N	N	Kenora
Bannockburn	Timmins	Abitibi	Ultramafic	Y	Y	Kirkland Lake
Boyer Lake	Dryden	Wabigoon	Mafic > Ultramafic	?	Y	Kenora
Bruce Lake	Red Lake	Uchi	Mafic	N	N	Red Lake
Buck Lake	Thunder Bay	Nipigon Plate	Mafic > Ultramafic	Y	Y	Thunder Bay South
Bulldozer	Hemlo	Wawa	Mafic >> Ultramafic	Y	Y	Thunder Bay South
Burchell Lake – N Shebandowan Lake	Shebandowan	Wawa	Mafic	Y	Y	Thunder Bay South
Caliper	Sioux Narrows	Wabigoon	Intermediate > Mafic	N	Y	Kenora
Caribou Lake	French River	Grenville	Mafic	Y	Y	Southeastern Ontario
Caribou Stock	Armstrong	Wabigoon	Mafic	N	Y	Thunder Bay North
Centre Hill Complex	Matheson	Abitibi	Ultramafic = Mafic	N	Y	Kirkland Lake
Chrome–Puddy Lake	Armstrong	Wabigoon	Ultramafic >> Mafic	N	Y	Thunder Bay South
Cobb Bay	Sturgeon Lake	Wabigoon	Ultramafic > Mafic	N	N	Kenora
Coldwell Complex	Hemlo	Wawa	Alkalic	Y	Y	Thunder Bay South
Copperfields	Temagami	Abitibi	Ultramafic = Mafic	N	Y	Kirkland Lake?
Crooked Green	Beardmore	Wabigoon	Mafic	N	N	Thunder Bay North
Crystal Lake	Thunder Bay	Nipigon Plate	Mafic	N	Y	Thunder Bay South
Cunningham–Garnet	Chapleau	Abitibi	Ultramafic < Mafic	N	N	Timmins
Dempster Lake	Pickle Lake	Uchi	Mafic	N	N	Thunder Bay North
Denmark Lake	Kenora	Wabigoon	Mafic	N	Y	Kenora
Dobie	Emo	Wabigoon	Mafic	N	N	Kenora
Dome–McDonough–Bateman property	Red Lake	Uchi	Ultramafic < Mafic	Y	Y	Red Lake
Dundonald	Matheson	Abitibi	Ultramafic = Mafic	Y	Y	Timmins
Eva Lake	Mine Center–Thunder Bay	Quetico	Ultramafic = Mafic	Y	Y	Thunder Bay South
Garden Lake intrusion	Thunder Bay–Armstrong	Wabigoon	Mafic	N	Y	Thunder Bay South
Garrison intrusion	Matheson	Abitibi	Ultramafic > Mafic	N	N	Kirkland Lake
Ghost Range Complex	Matheson	Abitibi	Ultramafic < Mafic	N	N	Kirkland Lake
Golden Arm	Red Lake	Uchi	Ultramafic < Mafic	?	Y	Red Lake
Gowski	Beardmore	Wabigoon	Mafic	N	N	Thunder Bay North
Grassy Portage	Mine Center	Wabigoon	Mafic	N	Y	Kenora
Grimsthorpe	Bancroft	Grenville	Mafic	N	N	Southeastern Ontario
Hains	Shebandowan	Wawa	Mafic	Y	Y	Thunder Bay South

Table 38.1. Continued

Intrusion Name	Area	Geologic (Sub)Province	Composition	Known PGE	Sulphides Observed	Resident Geologist District
Hammel Lake	Red Lake	Uchi	Mafic - Intermediate	N	N	Red Lake
Handcuff Lake	Sturgeon Lake	Wabigoon	Mafic	N	N	Kenora
Hele Township area	Thunder Bay	Nipigon Plate	Ultramafic >> Mafic	N	N	Thunder Bay South
Jackson Gabbro – Ledingham	Beardmore	Wabigoon	Mafic	N	N	Thunder Bay North
Jacobus	Beardmore	Wabigoon	Mafic - Intermediate	Y	Y	Thunder Bay North
July Falls	Pickle Lake	Uchi	Mafic	N	Y	Thunder Bay North
Junior Lake	Armstrong	Wabigoon	Ultramafic < Mafic	Y	Y	Thunder Bay North
Kakagi Lake	Kenora	Wabigoon	Mafic	N	N	Kenora
Kamiskotia	Timmins	Abitibi	Mafic	N	Y	Timmins
Kaweene Lake	Mine Center–Thunder Bay	Quetico	Ultramafic >> Mafic	Y	Y	Thunder Bay South
Killala Lake	Hemlo	Wawa	Mafic >> Ultramafic	?	Y	Thunder Bay South
Killer Creek	Bancroft	Grenville	Mafic	N	N	Tweed
Lake Abitibi	Matheson	Abitibi	Mafic	N	N	Timmins
Lash–Carpenter	Emo	Wabigoon	Mafic	N	N	Kenora
Lavant	Perth	Grenville	Mafic	N	N	Southeastern Ontario
Leo Lake – Donaldson Bay	Perth	Grenville	Mafic	N	?	Southeastern Ontario
Lower Caribou stock	Armstrong	Wabigoon	Mafic < Intermediate	N	N	Thunder Bay North
Mann intrusion	Timmins	Abitibi	Ultramafic = Mafic	Y	Y	Timmins
Marshall Lake	Beardmore	Wabigoon	Mafic	N	N	Thunder Bay North
McClintock	Dorset–Bancroft	Grenville	Ultramafic < Mafic	Y	Y	Southeastern Ontario
McVicar Lake	Pickle Lake	Uchi	Mafic	N	Y	Thunder Bay North
Montcalm	Timmins	Abitibi	Ultramafic < Mafic	Y	Y	Timmins
Moshkinabi	Hemlo	Wawa	Mafic	Y	Y	Thunder Bay South
Mountain Grove	Perth	Grenville	Mafic	N	N	Southeastern Ontario
Mud Lake	Mine Center–Thunder Bay	Quetico	Ultramafic >>Mafic	Y	Y	Thunder Bay South
Mulcahy	Kenora–Dryden	Wabigoon	Ultramafic < Mafic	Y	Y	Kenora
Munro	Matheson	Abitibi	Ultramafic > Mafic	N	N	Kirkland Lake
Musher Lake pluton	Hemlo	Wawa	Intermediate	?	?	Thunder Bay South
Nabish Lake	Dryden	Wabigoon	Mafic	N	Y	Kenora
Nickelbee Lake – Fire Lake dikes	Mine Center–Thunder Bay	Quetico	Ultramafic	Y	Y	Thunder Bay South
Nipissing gabbro – Basswood Lake	Sault Ste. Marie	Abitibi	Mafic	N	Y	Sault Ste. Marie
Nipissing gabbro – Bruce Mines – Thessalon	Sault Ste. Marie	Abitibi	Mafic	N	Y	Sault Ste. Marie
Nipissing gabbro – Karalash Corners	Sault Ste. Marie	Abitibi	Mafic	N	N	Sault Ste. Marie
Nipissing gabbro – Rose Township	Sault Ste. Marie	Abitibi	Mafic	N	N	Sault Ste. Marie

Table 38.1. Continued

Intrusion Name	Area	Geologic (Sub)Province	Composition	Known PGE	Sulphides Observed	Resident Geologist District
Nordica	Matheson	Abitibi	Ultramafic = Mafic	N	N	Kirkland Lake
North Elbow Lake	Mine Center–Thunder Bay	Quetico	Ultramafic = Mafic	N	N	Thunder Bay South
Nym Lake – Bergman intrusion	Mine Center–Thunder Bay	Quetico	Ultramafic	Y	Y	Thunder Bay South
O'Sullivan	Beardmore	Wabigoon	Mafic	N	N	Thunder Bay North
Otto stock	Kirkland Lake	Abitibi	Alkalic	N	Y	Kirkland Lake
Pakwash Lake	Red Lake	Uchi	Intermediate	N	N	Red Lake
Papineau	Mattawa	Grenville	Mafic	N	N	Southeastern Ontario
Pelletier	Hearst	Wawa	Mafic	N	Y	Timmins
Peterlong Lake	Timmins	Abitibi	Mafic	N	N	Timmins
Peterson property	Red Lake	Uchi	Ultramafic < Mafic	Y	Y	Red Lake
Pike Lake intrusion	Sturgeon Lake	Wabigoon	Mafic	N	N	Kenora
Pipestone Bay	Red Lake	Uchi	Ultramafic > Mafic	N	N	Red Lake
Pipestone Lake	Sioux Narrows	Wabigoon	Mafic	N	N	Kenora
Pure Gold gabbro	Red Lake	Uchi	Mafic	Y	Y	Red Lake
Raglan Hills	Bancroft	Grenville	Mafic	Y	Y	Southeastern Ontario
Rex–Werner–Bug lakes	Umfreville Lake	English River	Mafic > Ultramafic	Y	Y	Kenora
Roaring River – Allely	Thunder Bay–Armstrong	Wabigoon	Mafic - Intermediate	Y	N	Thunder Bay South
Ruffo Lake intrusion	Thunder Bay–Armstrong	Wabigoon	Mafic	N	N	Thunder Bay South
Samuels Lake	Mine Center–Thunder Bay	Quetico	Ultramafic > Mafic	Y	Y	Thunder Bay South
Shabotik	Hemlo	Wawa	Mafic > Ultramafic	Y	Y	Thunder Bay South
Shebandowan Mine	Shebandowan	Wawa	Ultramafic = Mafic	Y	Y	Thunder Bay South
Snakeweed Lake	Red Lake	Uchi	Mafic	N	Y	Red Lake
Sothman	Timmins	Abitibi	Ultramafic	Y	Y	Timmins
Sun Rise Lake	Wawa	Wawa	Ultramafic < Mafic	Y	Y	Timmins
Thierry Mine	Pickle Lake	Uchi	Ultramafic > Mafic	Y	Y	Thunder Bay North
Toronto Lake	Beardmore	Wabigoon	Ultramafic < Mafic	N	Y	Thunder Bay North
Trout Bay	Red Lake	Uchi	Ultramafic < Mafic	Y	Y	Red Lake
Tudor	Bancroft	Grenville	Mafic > Intermediate	N	N	Southeastern Ontario
White Lake	Hemlo	Wawa	Ultramafic < Mafic	N	Y	Thunder Bay South
Wolf Lake	Westport	Grenville	Mafic	N	N	Southeastern Ontario

Table 38.2. Description of geochemical analysis.

Analyte	Unit	DL	Method Name	Information Given by this Analyte
Al_2O_3	wt%	0.01	XRF–WD	*Identify and classify the rock using oxides or elements values *Identify and classify the rock using normative values *Determine magma type, suite, affinity *Describe magma evolution (source, partial melting, fractional crystallization, assimilation, mixing, alteration)
CaO	wt%	0.01		
Fe_2O_3	wt%	0.01		
K_2O	wt%	0.01		
MgO	wt%	0.01		
MnO	wt%	0.01		
Na_2O	wt%	0.01		
P_2O_5	wt%	0.01		
SiO_2	wt%	0.01		
TiO_2	wt%	0.01		
LOI	wt%	0.05		
Ni	ppm	3	XRF–WD pressed pellet	*These elements, along with Pt, Pd and Au, are controlled by the crystallization of olivine, pyroxene, chromite and sulphides, which makes them an excellent tool for the study of the evolution of a magma (partial melting, sulphide saturation and fractional crystallization)
Cu	ppm	4		
Co	ppm	9		
Cr	ppm	2		
S	wt%	0.01	XRF–WD	*Total sulphur concentrations or ratios of sulphur to metals are essential in describing the composition of the sulphides and the sulphide saturation history of the magma
Se	ppb	7	AAS	*S/Se ratios can indicate the source of sulphur (magmatic, host-rock assimilation, etc.), which is important in describing the processes and origin of mineralization
Y	ppm	2	XRF–WD pressed pellet	*In conjunction with Ti, these elements allow determination of the chemical affinity of the intrusion and the tectonic setting in which it was emplaced *These incompatible and relatively immobile elements are useful tracers of magma evolution especially when major elements have been affected by alteration or metamorphism
Zr	ppm	2		
Rb	ppm	2		
Sr	ppm	2		
Pt	ppb	0.5	ICP–AES	*These are the elements under study *Pt and Pd strongly fractionate into the sulphides, which makes these elements excellent markers for the history of sulphide saturation in the intrusion *Since Pd may be more mobile, the Pt/Pd ratio may indicate magmatic versus hydrothermal origin
Pd	ppb	0.9		
Au	ppb	0.9		

Abbreviations: DL, detection limit; XRF, X-ray fluorescence; WD, wavelength dispersive; AAS, atomic absorption spectrometry; ICP, inductively coupled plasma; AES, atomic emission spectroscopy

FINAL PROJECT PRODUCTS

The final products from this project are to be released in March and April 2002. They will include the following:

1. A digital map and database of magmatic nickel-copper ±PGE occurrences and mafic–ultramafic bodies in Ontario consisting of a CD-ROM with 3 separate products:
   1) a vector-based digital map of the geology of Ontario with all known magmatic nickel-copper ±PGE occurrences and sites of noteworthy mafic–ultramafic bodies available in GIS format, with associated geographically registered raster images representing the magnetic fabric (and its calculated vertical gradient), the Bouguer gravity field (and its calculated horizontal and vertical gradients), and lake sediment geochemistry of the province for the associated elements Ni, Cu, Co, and Cr. The raster images are included as layers with the mineral occurrences and mafic–ultramafic bodies superimposed;
   2) a lithogeochemical database in Microsoft Access® and Microsoft Excel®;
   3) a folder containing a Hewlett–Packard plot file (*.rtl) and Adobe files (*.pdf) of the main map.
   All new data generated by the summer 2001 field work and the analytical results on the samples collected will be integrated into the map and database as a distinct layer and entity relative to all the compiled data.
2. An Open File Report with the initial interpretations of the petrogenesis of the intrusions (e.g., source region, magma types) and their potential for PGE mineralization. This report will also list prospective intrusions and recommendations for further exploration work.

ACKNOWLEDGMENTS

The success of this project is due to the outstanding collaboration of geoscientists from the OGS Precambrian Geoscience Section and Resident Geologist Program, and also from various company geologists, prospectors and academics who gave us access to their property, diamond-drill core, grab samples or pulps. This greatly increased the efficiency of data collection, allowing the addition of a significant number of intrusions over and above the original list and enhancing the quality of products that will result from this project.

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39. Project Unit 01-304. Fertile Peraluminous Granites and Related Rare-Element Pegmatite Mineralization, Superior Province, Northwest and Northeast Ontario

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INTRODUCTION

The past year has witnessed a significant increase in exploration interest for rare-element mineral deposits in Ontario. This interest has led to widespread claim staking in most areas of the province where rare-element occurrences had been previously documented. The major impetus of this study has been linked to the surging price of tantalum, which, in 2000, was the top-performing metal the price of which increased 420%. The price of tantalum-niobium-rich concentrate (approximately 35 to 38% Ta_2O_5) rose from US$106 to $444 per pound in 2000 (www.metalworld.com) due to rising demand from the high technology and hard-metal applications coupled with a scarcity of supply. Approximately 60% of tantalum is utilized in the electronics industry and mainly in the form of tantalum capacitors (Tantalum-Niobium International Study Centre at www.tanb.org). The interest in tantalum as an exploration target in Ontario particularly heightened after publication of the article by A. Robinson "Little-known tantalum rare, but its future shines" (*The Globe and Mail*, January 5, 2001, p.B1-B2). Although the price of tantalum in the form of scrap vacuum solids (99.9% Ta) has retracted from its high of US$380 per pound, which was reached on December 19, 2000, the current price remains significantly higher at US$130 to $150 per pound as compared to a price of US$75 established in early 2000.

Past work in more localized areas of the Superior Province of Ontario has led to a proposed linkage between peraluminous, S-type, fertile parent granites and rare-element-rich pegmatites (e.g., Dryden area (Breaks and Moore 1992); Separation Lake area (Breaks and Tindle, in press)). Recognition of fertile peraluminous granites is critical in the exploration process as delineation of such granite masses effectively reduces the area of investigation. Most pegmatite swarms that can be linked with an exposed fertile, parent granite pluton are situated within approximately 15 km of such granites (e.g., Separation Rapids pluton and Eastern and Southwestern rare-element pegmatite groups: Breaks and Tindle, in press). However, in much of the vast Superior Province, there are negligible available data that are needed to chemically and mineralogically characterize potential peraluminous granite masses. Peraluminous, S-type granite masses are widespread in the English River, Quetico, and Opatica subprovinces, but also may occur in greenstone-rich subprovinces such as the Wabigoon and Sachigo subprovinces (e.g., Raleigh Lake area (Breaks 1993; Stone, Hallé and Chaloux 1999); North Caribou greenstone belt (Breaks, Osmani and DeKemp 2001).

The purpose of this project—part of the Operation Treasure Hunt initiative—is to initiate the development of a comprehensive field, chemical, mineralogical and geochronological database for fertile granites and associated rare-element pegmatites for the entire Superior Province of Ontario. Such a database is critical to future exploration success from the private sector. The work in the past field season focussed upon northwestern Ontario augmented by a small amount of work in northeastern Ontario (Figure 39.1).

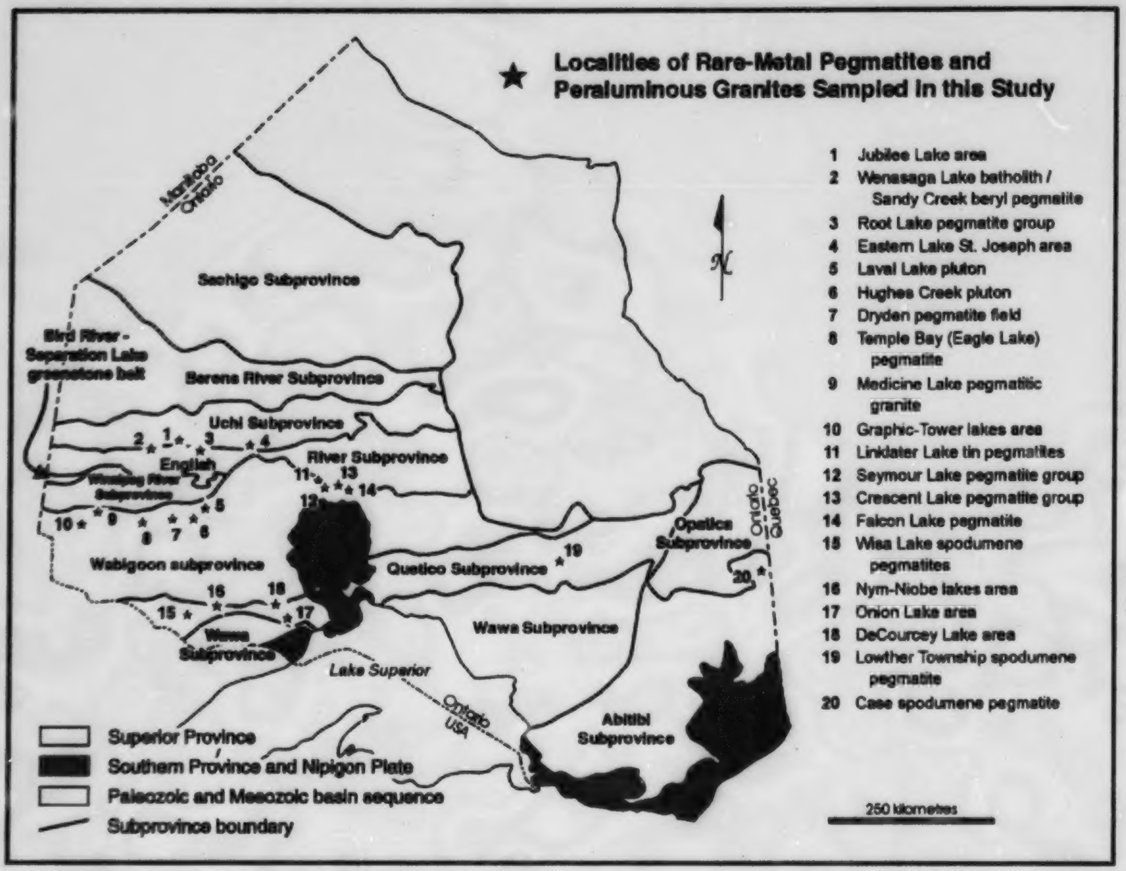
★ Localities of Rare-Metal Pegmatites and Peraluminous Granites Sampled in this Study
1 Jubilee Lake area
2 Wenasaga Lake batholith / Sandy Creek beryl pegmatite
3 Root Lake pegmatite group
4 Eastern Lake St. Joseph area
5 Laval Lake pluton
6 Hughes Creek pluton
7 Dryden pegmatite field
8 Temple Bay (Eagle Lake) pegmatite
9 Medicine Lake pegmatitic granite
10 Graphic-Tower lakes area
11 Linklater Lake tin pegmatites
12 Seymour Lake pegmatite group
13 Crescent Lake pegmatite group
14 Falcon Lake pegmatite
15 Wisa Lake spodumene pegmatites
16 Nym-Niobe lakes area
17 Onion Lake area
18 DeCourcey Lake area
19 Lowther Township spodumene pegmatite
20 Case spodumene pegmatite
N
Manitoba
Ontario
Sachigo Subprovince
Bird River - Separation Lake greenstone belt
Berens River Subprovince
Uchi Subprovince
English River Subprovince
Winnipeg River Subprovince
Wabigoon subprovince
Quetico Subprovince
Opatica Subprovince
Ontario
Quebec
Wawa Subprovince
Wawa Subprovince
Lake Superior
Ontario
USA
Abitibi Subprovince
Superior Province
Southern Province and Nipigon Plate
Paleozoic and Mesozoic basin sequence
Subprovince boundary
250 kilometres

Figure 39.1. Location of peraluminous pegmatitic granite masses and rare-element pegmatite mineralization examined in this study.

Several significant results have emerged from this study to date:

- discovery of rare-element mineralization in the Quetico Subprovince (Onion Lake and Nym–Niobe lakes areas)
- delineation of the largest fertile granite mass in northwest Ontario (Allison Lake batholith): a new, 15 by 50 km area is recommended for rare-element mineral exploration
- recognition that clastic metasedimentary rock-hosted tantalum pegmatites are widespread in the Sioux Lookout Domain: a 5 to 20 km by 160 km area is recommended for rare-element mineral exploration
- reclassification of McCombe dikes of Root Lake pegmatite group as complex-type, spodumene-subtype; the western Lake St. Joseph greenstone belt has high potential for tantalum mineralization
- established evolved tantalum-bearing and potassium feldspar mineralogy in the Onaman–Tashota greenstone belt of the Armstrong area; this belt represents an important new target area for tantalum and cesium deposits

Table 39.1. Average abundances and ranges of rare-elements and selected ratios from internal units of fertile granites in the Superior Province (Černý and Meintzer 1988, p.189) and upper continental crust values *from* Taylor and McLennan (1985).

	Average Upper Continental Crust (ppm)	**Internal Pegmatitic Granite Unit**					
		Fine-Grained Leucogranite		**Pegmatitic Leucogranite**		**Sodic Aplite**	
		Mean (ppm)	**Range (ppm)**	**Mean (ppm)**	**Range (ppm)**	**Mean (ppm)**	**Range (ppm)**
Be	3	4	<0.5–61	27	<0.5–604	6	1–34
Cs	3.7	8	<0.5–39	14	<0.5–51	16	<0.2–67
Ga	17	38	<10–81	20	<10–90	9	45–73
Li	20	81	1–1400	51.7	6–288	82	7–324
Nb	25	24	<1–81	18	<1–135		45–138
Rb	112	305	33–1050	473	32–5780	169	9–559
Sn	5.5	9	<1–44	19	<1–112	13	2–25
Ta	2.2	4.5	2–8.5	2.7	0.5–8		3–435
K/Cs	7630	11 000	794–78 400	7880	246–38 500	3020	166–14 900
K/Rb	252	159	42–418	165	13–576	85	24–332
Nb/Ta	11.4	5	0.1–11.9	1.71	0.1–7.17		0.32–0.62

The internal units of peraluminous pegmatitic granite masses and dikes, documented during this study, are classified according to Černý et al. (1981) and Černý and Meintzer (1988, p.178-180) as follows

- biotite and/or muscovite granite
- pegmatitic leucogranite
- potassic pegmatite
- fine-grained leucogranite
- sodic aplite

Table 39.1 provides some petrochemical data that typify three of the most abundant units of fertile granite bodies in the Superior Province (pegmatitic leucogranite, fine-grained leucogranite and sodic aplite) and is a useful guide in the chemical assessment of potential fertile granite masses. Classification of rare-element class pegmatite types and subtypes follows that of Černý (1989, 1991). Average upper continental crust values for Be (3 ppm), Cs (3.7 ppm), Ga (17 ppm), Li (20 ppm), Nb (25 ppm), Rb (112 ppm), Sn (5.5 ppm) and Ta (2.2), used as a reference in the assessment of degree of chemical evolution of fertile pegmatitic granites and related rare-element pegmatites, are from Taylor and McLennan (1985). Ratios of critical importance in assessing granite-pegmatite fractionation were also derived from the upper continental crust data (Taylor and McLennan 1985) as follows: K/Rb (252), K/Cs (7630), and Nb/Ta (11.4). Representative analyses of electron microprobe analyses and calculated atomic proportions for the oxide minerals and potassium feldspar, an important indicator mineral, from the localities investigated in this study are available in a Miscellaneous Release—Data (Tindle, Breaks and Selway 2001).

Unless otherwise noted, all analytical data presented in this report were provided by the Geoscience Laboratories, Ontario Geoservices Centre in Sudbury. All microprobe analyses of mineral phases were conducted by A.G. Tindle at Open University.

UCHI–ENGLISH RIVER SUBPROVINCIAL BOUNDARY ZONE

Rare-element pegmatite mineralization occurs over a 350 km strike length of this subprovincial boundary zone, from the Sandy Creek beryl pegmatite in the Ear Falls area east to the Lily Pad Lake complex-type pegmatite (Wallace 1978) in the Fort Hope area. Rare-element mineralization is also known in 3 intervening areas of this zone at Jubilee Lake, Root Lake and East Pashkokogan Lake (*see* Figures 39.2 and 39.6). Fertile peraluminous parent granites that generated rare-element mineralization in this boundary zone have thus far been postulated for the Wenasaga Lake batholith (Sandy Creek beryl pegmatite) and the Allison Lake batholith (Jubilee Lake pegmatite group and possibly the Root Lake pegmatite group).

Jubilee Lake Area

ALLISON LAKE BATHOLITH

Work in this area focussed upon the Allison Lake batholith (Figure 39.2). Previous geological work (Bateman 1939; Breaks et al. 1976, 1979; Thurston 1985a, 1985b) had covered only small parts of this extensive, 16 by 40 km, tadpole-shaped peraluminous, pegmatitic granite body. Breaks et al. (1976, 1979) delineated most of the southeast-striking tail of the pluton that was designated on their map as a "pegmatite zone". Thurston (1985a, p.60), who named the pluton, mapped small areas of the batholith along its western contact with the Jubilee Lake metasedimentary unit in the Allison–Margaret lakes area. A reconnaissance delineation of the batholith was undertaken by this survey and revealed the largest known fertile, peraluminous granite in northwestern Ontario. Gupta and Wadge (1986), as part of a regional gravity survey, completely covered the Allison Lake batholith. A significant –680 to –700 mgal Bouguer gravity low, named the "Allison–Sesikinaga low", corresponds to the main mass of the batholith (Gupta and Wadge 1986). Gravity modelling suggests that the batholith is 8 km thick and extends north underneath the Jubilee Lake metasedimentary rocks (Gupta and Wadge 1986).

Petrography and Mineralogy of Internal Units

Granitic units of the Allison Lake batholith comprise white weathered, muscovite and biotite-muscovite potassic pegmatite, pegmatitic leucogranite and fine-grained leucogranite that are intermittently layered with fine- to medium-grained biotite granite, biotite-muscovite granite, garnet-muscovite granite and sodic aplite. Widespread accessory minerals include black tourmaline, garnet and apatite. The pegmatitic leucogranite commonly contains plumose muscovite-quartz intergrowth, as near Jubilee Lake (UTM co-ordinates: 544160E, 5653844N; Zone 15) that are typical for fertile granite plutons (e.g., Separation Rapids pluton (Breaks and Tindle, in press)). Quartz-rich patches represent a minor, but widespread, unit within potassic pegmatite or pegmatitic leucogranite. Such quartz-rich domains were conducive to development of coarse blocky potassium feldspar crystals in the 30 to 100 cm diameter range. Beryl crystals occur sporadically in the quartz-rich patches, as at Curie Lake. Veins and dikes of potassic pegmatite represent minor units that transect the fine- to medium-grained granite units.

Tourmaline is a widespread accessory phase, however, its greatest abundance occurs in the Peg Lake area near the western contact of the batholith. Locality 01FWB-28 (UTM co-ordinates: 542668E, 5663342N, Zone 15) consists dominantly of tourmaline-muscovite potassic pegmatite that grade into quartz-rich patches with increased tourmaline abundance and grain size (up to 3 by 5 cm cross-sections and 2 by 16 cm in prismatic sections). Tourmaline-muscovite pegmatitic leucogranite at Curie Lake contains relatively abundant black tourmaline (5%) that grades into medium- to coarse-grained biotite granite. The tourmaline also occurs in quartz-rich patches where it is associated with sporadic light green beryl.

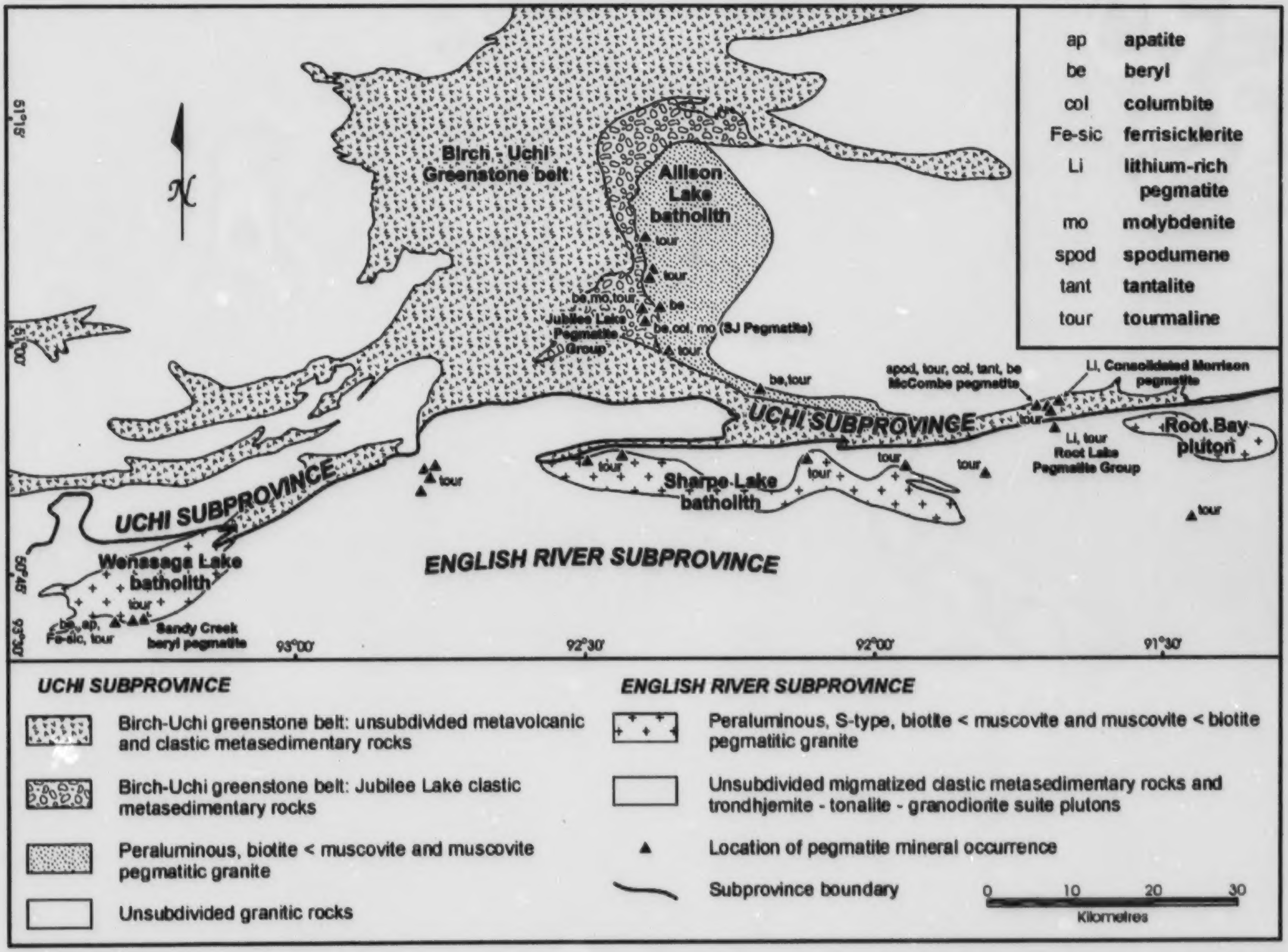
ap apatite
be beryl
col columbite
Fe-sic ferrisicklerite
Li lithium-rich pegmatite
mo molybdenite
spod spodumene
tant tantalite
tour tourmaline
N
51°15'
51°00'
50°45'
93°30'
93°00'
92°30'
92°00'
91°30'
Birch - Uchi Greenstone belt
Allison Lake batholith
tour
be,mo,tour
be
Jubilee Lake Pegmatite Group
be,col, mo (SJ Pegmatite)
be,tour
spod, tour, col, tant, be McCombe pegmatite
Li, Consolidated Morrison pegmatite
UCHI SUBPROVINCE
Li, tour Root Lake Pegmatite Group
Root Bay pluton
Sharpe Lake batholith
Wenasaga Lake batholith
be, ap, Fe-sic, tour
Sandy Creek beryl pegmatite
ENGLISH RIVER SUBPROVINCE
UCHI SUBPROVINCE
Birch-Uchi greenstone belt: unsubdivided metavolcanic and clastic metasedimentary rocks
Birch-Uchi greenstone belt: Jubilee Lake clastic metasedimentary rocks
Peraluminous, biotite < muscovite and muscovite pegmatitic granite
Unsubdivided granitic rocks
ENGLISH RIVER SUBPROVINCE
Peraluminous, S-type, biotite < muscovite and muscovite < biotite pegmatitic granite
Unsubdivided migmatized clastic metasedimentary rocks and trondhjemite - tonalite - granodiorite suite plutons
Location of pegmatite mineral occurrence
Subprovince boundary
0 10 20 30
Kilometres

Figure 39.2. General geology and location of peraluminous pegmatitic granite masses and associated rare-element mineralization in the English River–Uchi subprovincial boundary zone between western Lake St. Joseph and Ear Falls (geology *compiled from* Thurston (1985a, 1985b) and Breaks and Bond (1993)).

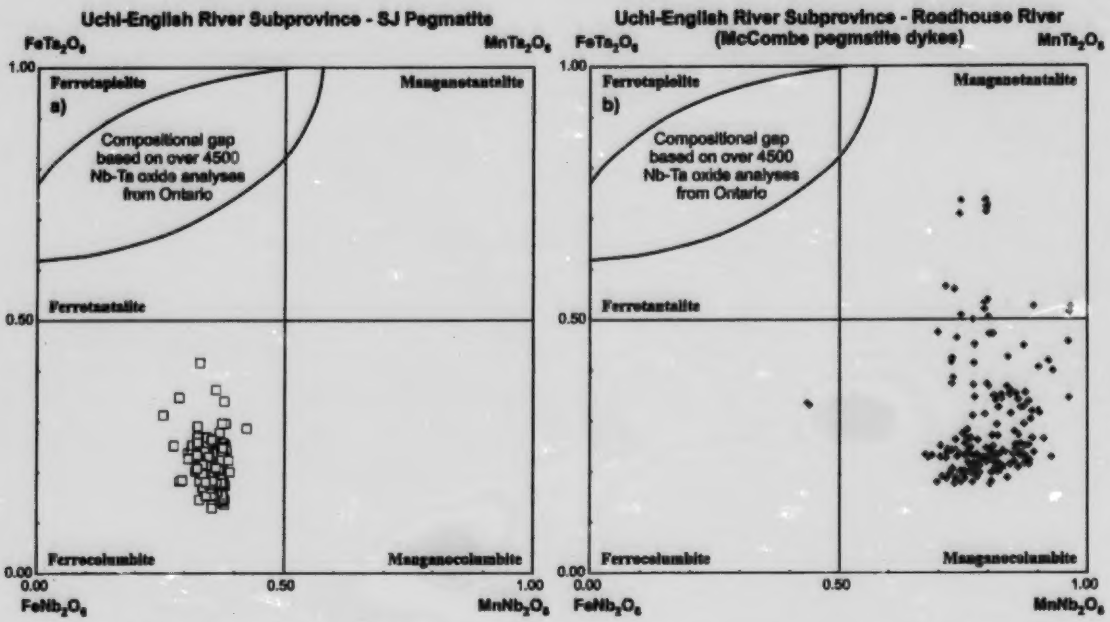

Figure 39.3. Columbite–tantalite quadrilateral plot for SJ beryl-type pegmatite (Jubilee Lake group) and McCombe complex-type pegmatite Dikes 1 and 2 (Root Lake group).

Jubilee Lake Pegmatite Group

Rare-element pegmatite mineralization was initially discovered near Jubilee Lake by prospector Stan Johnson in 1964. Recently, additional beryl mineralization was discovered by prospector Sherridon Johnson, a short distance to the north. A third beryl-bearing, tourmaline-muscovite pegmatite dike, 12 to 95 cm thick, was noted during the present survey (UTM co-ordinates: 542209E, 5654674N; Zone 15). The cluster of these 3 beryl-type pegmatites has been named the Jubilee Lake pegmatite group by the authors (*see* Figure 39.2). A fourth beryl occurrence was found by the writers on the eastern shoreline of Curie Lake (UTM co-ordinates: 556180E, 5644559N; Zone 15), 11.5 km southeast of Jubilee Lake, as a single 5 cm diameter light green crystal in a quartz-rich patch within a tourmaline-rich pegmatitic leucogranite.

SJ PEGMATITE

The SJ pegmatite (UTM co-ordinates: 542529E, 5653027N; Zone 15) represents the largest pegmatite in the group and is exposed over a minimum area of 35 by 30 m. It likely represents an exocontact dike hosted in metasedimentary rocks, although no external intrusive contacts were obvious. The pegmatite consists of apatite-garnet-muscovite-potassium feldspar-quartz-albite with local quartz-rich patches that contain light pink blocky potassium feldspar crystals up to 30 by 50 cm. Irregular, lime green replacement masses of muscovite-albite are obvious in the largest blast pit and contain abundant black, platy tantalum-niobium oxide minerals. A large bulk rock sample of the oxide-bearing unit returned 173 ppm Ta. Electron microprobe analyses (114) of the oxide minerals indicate that they exclusively lie in the ferrocolumbite field (Figure 39.3), but reveal an iron-rich fractionation trend marked by a modest increase in Ta_2O_5 (mean = 24.78% Ta_2O_5; range = 15.47 to 38.79% Ta_2O_5).

White to faint green beryl crystals reach up to 6 cm in diameter. A bulk analysis of several beryl crystals revealed 78 ppm Rb, 477 ppm Cs and 1350 ppm Li.

Bulk Chemistry

Initial results from 17 rock bulk samples collected from various internal units across the Allison Lake batholith reveal anomalous lithium levels in numerous samples. An overall mean of 78 ppm Li was observed within a range of 9 to 190 ppm Li. A significant areal distribution of lithium within the Allison Lake batholith is also obvious. The western contact zone of the pegmatitic granite, situated within 1.5 km of the Jubilee Lake metasedimentary rocks—in addition to the narrow southeastern tail—contain the highest lithium levels. These data support an increase in pegmatite evolution towards these parts of the batholith ($\text{mean}_{11} = 90$ ppm Li *versus* a $\text{mean}_6 = 41$ ppm Li for areas of the batholith outside these two zones). Such lithium values fall within the mean content for various internal units from fertile peraluminous granites elsewhere in the Superior Province (Černý and Meintzer 1985, p.189).

Rare-Element Exploration Potential

The Allison Lake fertile pegmatitic granite represents an important new exploration target for rare-element mineralization. A large area is highly recommended for follow-up exploration and involves a 15 by 50 km corridor that follows the western to southwestern contact of the batholith (from Bumpy Lake in the north to Curie Lake near the southeastern termination, *see* Figure 39.2). This area has high potential for further discoveries of rare-element mineralization that could occur in exocontact, metasedimentary-hosted pegmatites or as internal pegmatites within the parent granite. Only beryl-type pegmatites have been discovered to date, however, in light of the common regional zonation sequence of rare-element pegmatites from beryl- into lithium-rich types (albite-spodumene-type and complex-type), this corridor is recommended for detailed exploration. The high potential for tantalum mineralization is highlighted by the economically interesting bulk rock tantalum value of 173 ppm Ta obtained by the authors at the SJ pegmatite.

Wenasaga Lake Batholith

This peraluminous, S-type granite mass, 7 by 26 km, was delineated by Breaks and Bond (1993) and is elongate concordant to the Uchi–English River subprovincial boundary (*see* Figure 39.2). The batholith was examined for potential linkage with metasedimentary-hosted rare-element pegmatite mineralization as a beryl-type pegmatite is situated proximal to the southwestern flanks of the batholith.

The Wenasaga Lake batholith consists of a variety of pegmatitic granite units that are consistent with other fertile granite plutons. These massive to foliated and locally cataclastic units include white weathered, medium- to coarse-grained, biotite-muscovite pegmatitic leucogranite, biotite- and muscovite < biotite, biotite < muscovite granite. The granite units are particularly abundant in the southwestern part of the batholith and are well exposed in a blast cut along the former Griffith iron mine rail line near Detector Lake (UTM co-ordinates: 475959E, 5619076N; Zone 15). At this location, biotite-muscovite pegmatitic leucogranite grades into muscovite < biotite granite that contains local enclaves of metatexite metasedimentary migmatite. Sparse symplectites of cordierite-quartz occur in the granite where the cordierite has largely been converted into mica-rich pseudomorphs. Such symplectites are widespread in peraluminous, S-type granites of the English River Subprovince (Breaks 1991) and also in parts of the Quetico Subprovince examined in this study. Apatite is a particularly widespread accessory phase and is notably abundant in the phosphorus-rich pegmatite pods within the Sandy Creek beryl dike.

A late episode of aluminum enrichment is evident as closely spaced, deformed veins, 1 to 2 cm in thickness, that are composed essentially of grey fibrolite, muscovite, biotite and local apatite, are present. The high aluminum veins are crosscut by undeformed veins of black tourmaline-quartz. Genetic connection of these vein emplacement episodes with rare-element-mineralization is possible and requires a more detailed examination.

RELATED RARE-ELEMENT MINERALIZATION

To date, rare-element mineralization spatially associated with the Wenasaga Lake batholith has only been found at the Sandy Creek beryl dike (Figure 39.4). This dike, which is metasedimentary hosted, is classified as beryl-type, phosphate-subtype (Černý 1991). The mineralized system, which includes related *en échelon* smaller pegmatite dikes, occupies a minimal area of 20 by 60 m in an area of generally poor exposure. The main pegmatite dike, which strikes 090° and dips from 65 to 85° to the north, varies from 1 to 2.5 m and bifurcates near its west end (*see* Figure 39.4).

Most of the dike comprises a white to light pink, quartz-megacryst-bearing, sodic aplite that is subtly foliated. Fine-grained cleavelandite is the dominant mineral and composes about 70 to 80% of the mode. Field relations and petrographic observations indicate that the aplite is of primary origin. There is no field evidence that supports late-stage, subsolidus albitization responsible for the high sodium contents. Minor phases in the aplite include large books of muscovite, dark green apatite, white beryl and black tourmaline. Oxide minerals have not been observed to date, but could be inconspicuous due to fine grain size.

Pods of phosphate-rich pegmatite occur predominantly along the northern contact where spectacular masses of friable, chocolate-brown, weathered ferrisicklerite [$Li(Fe^{+3}, Mn^{+2}) PO_4$] are complexly intergrown with dark green apatite and comprises about 20% of the mode. This locality is the first documented occurrence for ferrisicklerite in the Superior Province of Ontario. Elsewhere, ferrisicklerite has been mainly observed as a "late hydrothermal alteration or replacement of triphylite-lithiophilite in complex, zoned pegmatites" (Anthony et al. 2000) as, for example, in the complex-type, petalite-subtype, Varutrask pegmatite of northern Sweden. Primary phosphates other than apatite have yet to be recognized in the Sandy Creek pegmatite. Beryl, as faint green to white crystals up to 7 cm in diameter, attains its highest concentration in the pegmatite unit.

Black tourmaline concentrations in domains up to 0.8 by 3 m in size are intermittently obvious along the northern contact (*see* Figure 39.4), where metawacke host rocks contain 50 to 60% tourmaline porphyroblasts that are randomly oriented relative to foliation.

BULK CHEMISTRY

Lithium contents in granitic rocks of the Wenasaga Lake batholith are mainly below 40 ppm. However, the mean value of 43 ppm Li and its range of 9 to 170 ppm Li are based upon a small population of 7 samples. The Sandy Creek beryl dike contains higher lithium levels and a much wider range of 28 to 3544 ppm Li. The primary cleavelandite-rich aplite is characterized by high Na_2O (9.40 to 9.46%) that contrasts with the phosphate-rich, pegmatite pods with much lower Na_2O (1.47%) and considerably higher P_2O_5 (10.17%). The highest lithium level of 3533 ppm (0.75% Li_2O) was also found in the phosphate-rich pegmatite units and represents a concentration that is unusual for beryl-type pegmatites that typically have negligible lithium levels.

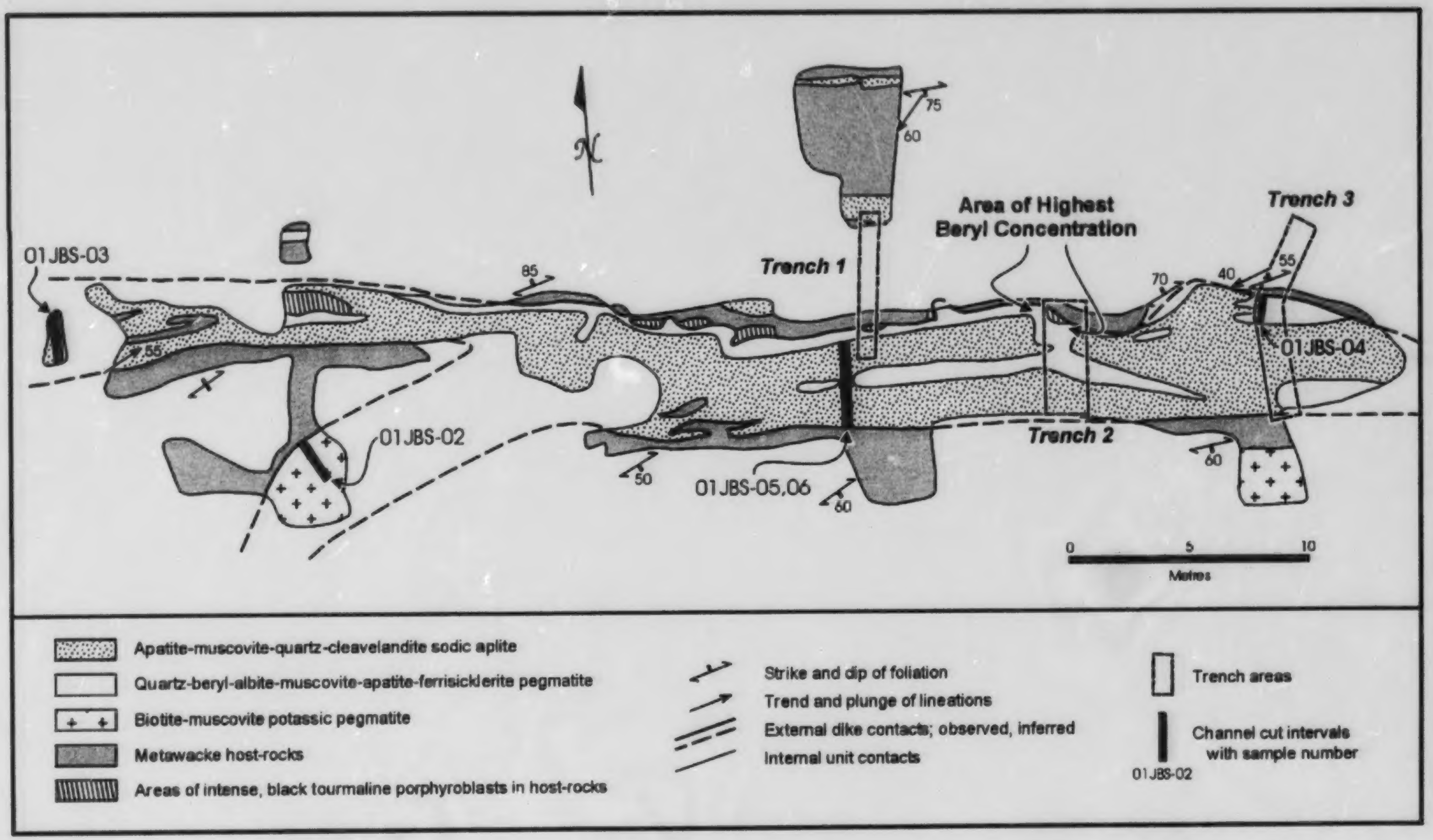
Trench 1
Trench 2
Trench 3
Area of Highest Beryl Concentration
01JBS-03
01JBS-02
01JBS-05,06
01JBS-04
85
55
50
60
75
60
70
40
55
60
N
0
5
10
Metres
Apatite-muscovite-quartz-cleavelandite sodic aplite
Quartz-beryl-albite-muscovite-apatite-ferrisicklerite pegmatite
Biotite-muscovite potassic pegmatite
Metawacke host-rocks
Areas of intense, black tourmaline porphyroblasts in host-rocks
Strike and dip of foliation
Trend and plunge of lineations
External dike contacts; observed, inferred
Internal unit contacts
Trench areas
Channel cut intervals with sample number
01JBS-02

Figure 39.4. Detailed geology of the Sandy Creek beryl dike and sample sites of this study.

RARE-ELEMENT EXPLORATION POTENTIAL

Grab samples previously collected over the exposed area of the Sandy Creek pegmatite revealed less than 30 to 240 ppm Ta (Breaks and Bond 1993). The present survey documented a mean tantalum content of 7.27 ppm within a range of 1.12 to 15.62 ppm Ta in 5 channel cuts distributed across an exposed strike length of dike. Although tantalum values are low in the aplite and ferrisicklerite pegmatite, the Nb/Ta ratios average 3.14 and range from 1.29 to 7.6, which indicates significant fractionation between niobium and tantalum relative to the average upper continental crust ratio of 11.4 (Taylor and McLennan 1985). These data indicate that the dike should be carefully checked for tantalum-rich zones at depth in addition to the possibility of vertical internal zonation. The dominant cleavelandite-rich, aplite could represent a sodium-rich cupola zone that grades into lithium-rich pegmatite at depth. Such lithium zones could contain higher levels of tantalum.

Rare-element pegmatites commonly occur in zoned swarms of many individual pegmatites, therefore, exploration in the 10 km^2 area around the Sandy Creek dike should be focussed on the potential for lithium- and tantalum-rich pegmatites of the albite-spodumene- and complex-type. Such pegmatites could be concealed by the extensive overburden of the area and, hence, were not detected in previous surface prospecting.

Root Lake Pegmatite Group

The Root Lake pegmatite group has been renamed from "Root Lake Field" of Mulligan (1965) in accordance with terminology of Černý et al. (1981). This group was discovered during the lithium rush of the 1950s (Pye 1956; Mulligan 1965) and comprises 4 spodumene pegmatites within a 3 by 4 km area that are hosted both in mafic metavolcanic rocks of the Lake St. Joseph belt (Clifford 1969) and metasedimentary rocks of the English River Subprovince (Breaks et al. 1979). Genetic linkage with fertile granite plutons has not been definitely established, however, these pegmatites lie proximal to the chemically evolved southeast arm of the Allison Lake batholith (*see* Figure 39.2). The Root Bay pluton, a peraluminous, S-type granite is also situated near the pegmatite group (*see* Figure 39.2) and could represent a parental source for the lithium-rich pegmatites.

RARE-ELEMENT MINERALIZATION

McCombe Pegmatite Dikes 1 and 2

Considerable exploration for lithium was undertaken in 1956 on these two dikes that were traced on surface for a strike length of 550 m. Diamond drilling (55 holes that totalling 10 442 m) established 2.297 million tons grading 1.3% Li_2O (Mulligan 1965, p.64). The best exposed part of these pegmatite dikes, situated toward the west end, have been mapped and described by Breaks and Bond (1993).

Several internal units were observed in the two pegmatites (Figure 39.5):

- tourmaline-bearing, potassium feldspar porphyritic spodumene pegmatite
- tourmaline-bearing, equigranular to potassium feldspar-porphyritic, sodic aplite
- white feldspar-rich wall zone
- tourmalinite along dike contacts
- lepidolite-rich pods and seams.

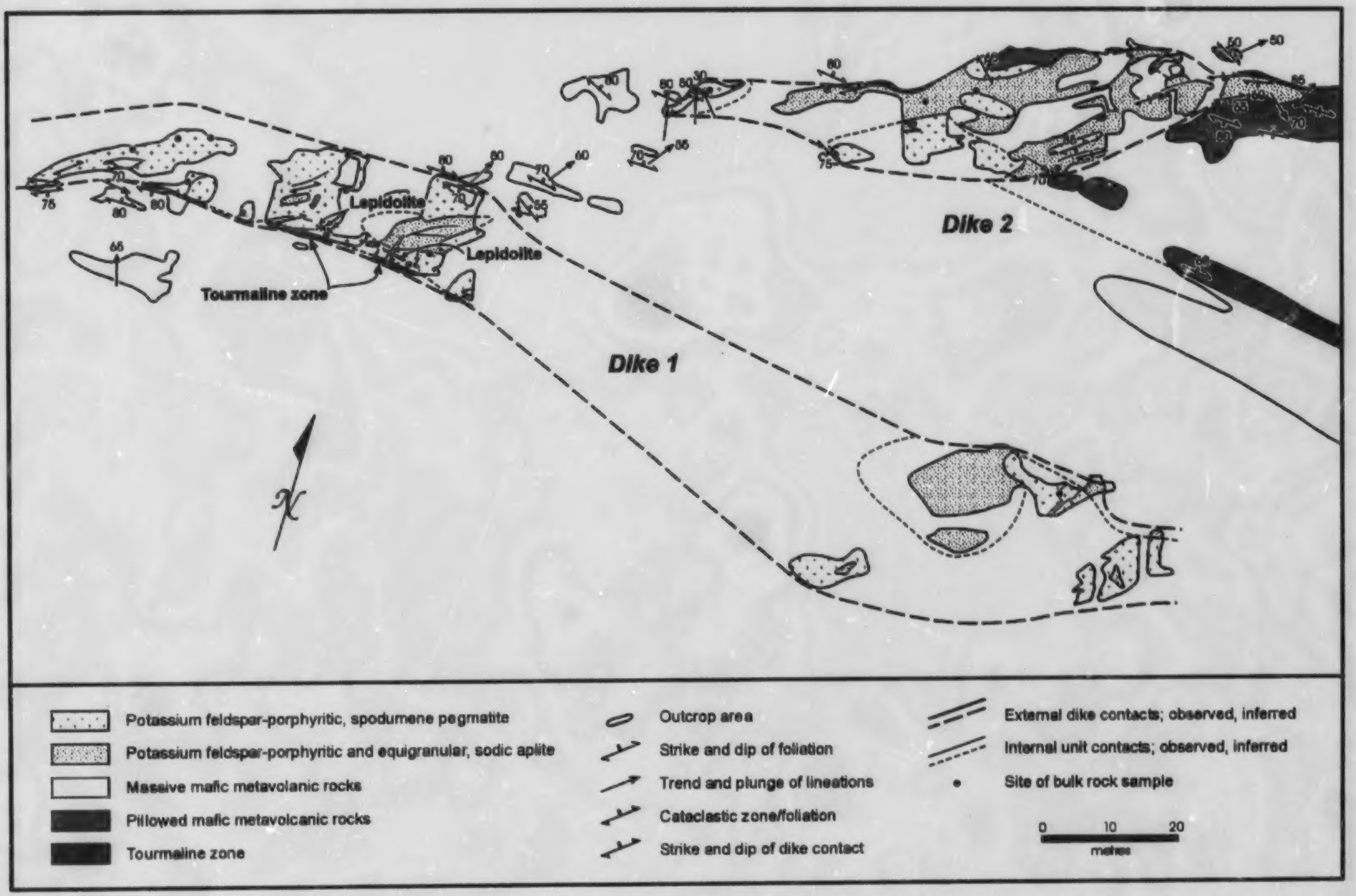
Dike 1
Dike 2
Lepidolite
Lepidolite
Tourmaline zone
N
Potassium feldspar-porphyritic, spodumene pegmatite
Potassium feldspar-porphyritic and equigranular, sodic aplite
Massive mafic metavolanic rocks
Pillowed mafic metavolcanic rocks
Tourmaline zone
Outcrop area
Strike and dip of foliation
Trend and plunge of lineations
Cataclastic zone/foliation
Strike and dip of dike contact
External dike contacts; observed, inferred
Internal unit contacts; observed, inferred
Site of bulk rock sample
0
10
20
metres

Figure 39.5. Detailed geology and sample sites at McCombe complex-type pegmatite Dikes 1 and 2 in Root Lake pegmatite group.

Dike 1 is the largest and is intermittently exposed for a strike length of 176 m and maximum width of 15 m. Dike 2 is lens-shaped in plan and measures 19 by 87 m. Highly deformed mafic metavolcanic rocks comprise the host rocks that contain local, acicular, purple holmquistite crystals formed due to lithium metasomatism from the pegmatites. Armenite ($BaCa_2Al_6Si_9O_{30}{\cdot}2H_2O$) was also found in mafic metavolcanic host rocks near Dike 1 and is likely the first occurrence documented in the Superior Province of Ontario.

Twenty-four bulk rock samples selected across the 2 dikes (*see* Figure 39.5) gave a mean of 91 ppm Ta and a range of 30 to 380 ppm Ta. The highest tantalum value occurs in a tourmaline aplite pod contained within spodumene-rich pegmatite.

MINERAL CHEMISTRY

An extensive electron microprobe investigation of various minerals (1796 analyses) from the McCombe pegmatite dikes has revealed a highly evolved rare-element system. The pegmatites have been classified as complex-type, spodumene-subtype on the basis of highly evolved potassium feldspar chemistry, coupled with the presence of local petalite, microlite, lepidolite, lithium-calcium liddicoatite, the latter representing the most evolved lithium tourmaline composition yet found in the Superior Province of Ontario. Potassium feldspar has average Rb_2O and Cs_2O values of 1.59% and 0.09%, respectively.

The oxide minerals, examined during 205 electron microprobe analyses, consist dominantly of manganocolumbite with subordinate manganotantalite and rare ferrocolumbite and microlite (*see* Figure 39.3). The columbite-tantalite group minerals lie on the manganese-rich trend of Tindle and Breaks (1998). Oxide minerals in Dike 1 have a mean content of 29.32% Ta_2O_5 and range of 20.12 to 69.09% Ta_2O_5. Oxide minerals in Dike 2 have a mean Ta_2O_5 content of 37.58% and a range of 22.97 to 68.51% Ta_2O_5.

Lepidolite is highly evolved as indicated by levels of Rb_2O (2.72%) and Cs_2O (0.82%), which are comparable to that of the Tanco pegmatite (Tanco Mine, Lac du Bonnet, Manitoba), where the highest values are 3.93% Rb_2O and 0.79% Cs_2O (Rinaldi, Černý and Ferguson 1972).

MINERAL EXPLORATION POTENTIAL

The newly classified, complex-type pegmatites in the Root Lake pegmatite group renders the mafic metavolcanic and adjacent low- to medium-grade metasedimentary rocks of the English River Subprovince, in the Root Lake area, an area of high potential for tantalum-rich pegmatite deposits. Exploration should focus upon lithochemical techniques, as detailed below, in order to detect blind pegmatite mineralization.

Previous exploration for lithium in the 1950s may have disregarded aplite dikes that are barren of spodumene during routine prospecting. However, such dikes constitute highly favourable targets for tantalum, therefore, the entire area should be prospected thoroughly with a focus on aplite and sodic pegmatite dikes that could host inconspicuous, but potentially economic, concentrations of tantalum-niobium-rich oxide minerals.

Lithochemical Exploration

Widespread black tourmaline-quartz veins and adjacent tourmaline porphyroblasts were observed in mafic metavolcanic rocks exposed along a roughed-in logging road that crosses the mid-part of the pegmatite group and provides a 1.5 km section normal to the strike of foliation. These undeformed, tourmaline-quartz veins are typically 1 to 2 cm thick and oriented discordant to foliation of the host rocks. Five samples of foliated mafic metavolcanic rocks and 2 samples of tourmaline-quartz veins gave respective lithium ranges of 15 to 98 ppm and 47 to 328 ppm. A progressive increase in lithium content was also noted in a northerly direction along the road. The highest values of lithium were documented at locality 01FWB-41 (UTM co-ordinates: 591763E, 5643280N; Zone 15) that occurs approximately 1 km east of the McCombe pegmatite dikes. A 1 m thick tourmaline-bearing quartz-porphyritic aplite dike from this locality also contains anomalous lithium (98 ppm) and could represent an apophysis of a lithium pegmatite system.

It would appear from this small sample population that lithium lithochemistry could be an effective geochemical tool in the exploration for mafic metavolcanic rock-hosted rare-element pegmatites in the Root Lake area. Tourmaline-rich vein chemistry, which has not been utilized in exploration to the authors' knowledge, may potentially be useful as a guide to finding exposed or blind rare-element pegmatite deposits in the area as tourmaline is present in the McCombe pegmatites and in veins in the surrounding mafic metavolcanic rocks.

Eastern Lake St. Joseph Area

This area of the Uchi–English River subprovincial boundary zone has potential for rare-element pegmatite mineralization owing to widespread peraluminous pegmatite dikes that, in part, may be related to large pegmatitic granite plutons (Twiname Lake and Caron Lake plutons: Kay and Stott 1985; Stott 1996). A detailed account of these rocks and their preliminary geochemical evaluation is given by Kay and Stott (1985) and the reader is referred to this report. The present survey undertook a brief investigation of pegmatite dikes in the eastern Lake St. Joseph and the East Pashkokogan Lake lithium occurrence (Figure 39.6).

PERALUMINOUS GRANITE PLUTONS

The 65 km^2 Twiname Lake and 145 km^2 Caron Lake pegmatitic granite plutons represent the largest such masses delineated in the area (Kay and Stott 1985). Numerous small pegmatite dikes, 6 to 70 m thick, occur in the Soules Bay–Doghole Bay area of eastern Lake St. Joseph and may have been generated by these 2 plutons. For example, at locality 01JBS-19 (UTM co-ordinates: 692310E, 5668455N; Zone 15), an extensively sheared and boudinaged white pegmatite dike is contained in a metawacke host (*see* Figure 39.6). This 3 to 5 m thick dike is mostly composed of muscovite-rich potassic pegmatite that grades into quartz-rich patches with blocky potassium feldspar. Minor garnet aplite was also noted. Preliminary petrochemical data indicate modest chemical evolution for the potassic pegmatite as indicated by a lithium content of 67 ppm. A pegmatite dike investigated by Kay and Stott (1985, p.33, sample 0075B) is situated 3 km to the east and contains anomalous levels of most rare-elements, such as 50 ppm Cs, 36 ppm Nb, 23 ppm Ta, 15 ppm Be and 5 ppm Li.

Tourmaline within pegmatite dikes and adjacent exomorphic aureoles developed in metasedimentary and metavolcanic host rocks was noted by Kay and Stott (1985, p.33-34). A significant example occurs on a small island (UTM co-ordinates: 686483E, 5660530N; Zone 15) about 2 km west of the entrance of Ace Lake where a 10 m thick, light pink dike of tourmaline-muscovite pegmatitic leucogranite is emplaced

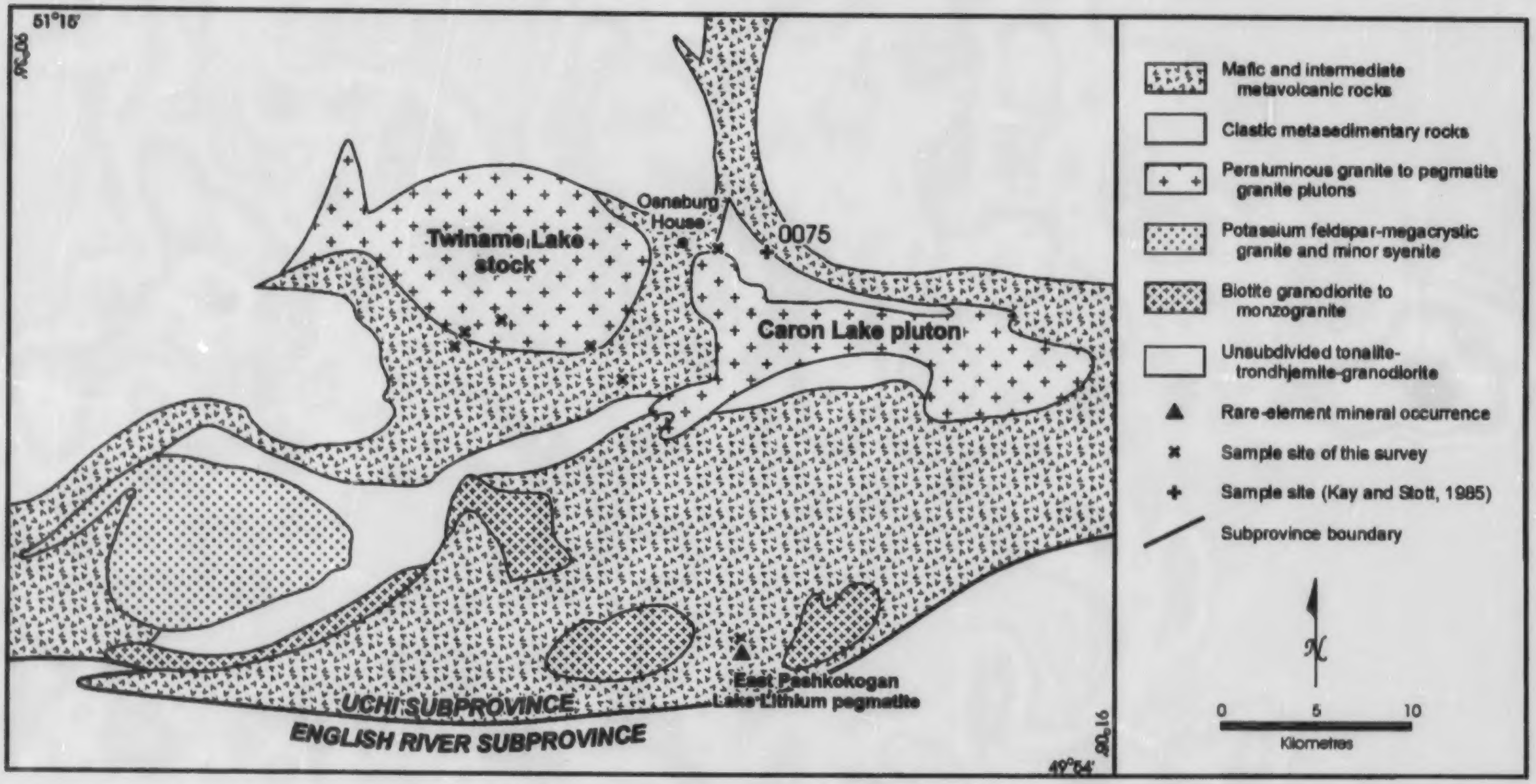
51°15'
90°36'
Twiname Lake stock
Osnaburg House
0075
Caron Lake pluton
East Pashkokogan Lake Lithium pegmatite
UCHI SUBPROVINCE
ENGLISH RIVER SUBPROVINCE
91°06'
49°54'
Mafic and intermediate metavolcanic rocks
Clastic metasedimentary rocks
Peraluminous granite to pegmatite granite plutons
Potassium feldspar-megacrystic granite and minor syenite
Biotite granodiorite to monzogranite
Unsubdivided tonalite-trondhjemite-granodiorite
Rare-element mineral occurrence
Sample site of this survey
Sample site (Kay and Stott, 1985)
Subprovince boundary
N
0
5
10
Kilometres

Figure 39.6. General geology, location of peraluminous granites, rare-element mineralization and sample sites in eastern Lake St. Joseph area (geology *after* Stott 1996).

into foliated mafic metavolcanic rocks. The dike contains impressive single and radiating clusters of black tourmaline up to 2 by 23 cm; and graphic intergrowths of quartz-potassium feldspar megacrysts up to 35 by 50 cm. The pegmatite contact is characterized by an 8 cm thick exomorphic aureole composed of tourmaline, biotite and muscovite.

The Twiname Lake pluton is an ovoid, 9 by 15 km, pegmatitic granite mass that is dominated by biotite < muscovite and muscovite < biotite pegmatitic leucogranite. This unit is gradational into pockets of potassic pegmatite, quartz-rich patches and layers of garnet-biotite, fine-grained leucogranite. Slender biotite-rich blades typically developed in radiating aggregates ("crowfoot texture") were noted at locality 01JBS-24 (UTM co-ordinates: 687617E, 5663609N; Zone 15) on Lake St. Joseph and represents a texture commonplace in fertile granite plutons (Černý et al. 1981). The Caron Lake pluton, in contrast, is fine to medium grained, contains muscovite, biotite, local garnet and tourmaline (Kay and Stott 1985).

RARE-ELEMENT MINERALIZATION

The only rare-element occurrence known in the eastern Lake St. Joseph area is the East Pashkokogan Lake spodumene pegmatite (Goodwin 1965; Kay and Stott 1985). Goodwin (1965, p.55) reported an average of 1.25% Li_2O in a chip sample across the exposed 16 m width of the pegmatite. Kay and Stott (1985, p.30, p.32-33) mapped the pegmatite in detail and delineated a northeast-striking layering of spodumene pegmatite and aplite. Five grab samples, taken by these workers, gave an average of 33 ppm Ta within a range of 16 to 80 ppm Ta. The pegmatite was sampled by this survey for mineral chemistry characterization and bulk tantalum content.

MINERAL EXPLORATION POTENTIAL

Exploration for rare-element mineralization is warranted in the eastern Lake St. Joseph area in vicinity of the Twiname Lake and Caron Lake pegmatitic granite plutons. This recommendation is based upon previous work of Kay and Stott (1985) and Stott (1996), in addition to modestly evolved pegmatites documented during the present survey.

SIOUX LOOKOUT DOMAIN (WABIGOON–WINNIPEG RIVER BOUNDARY ZONE)

Rare-element mineralization is distributed along a 70 km strike length of the Sioux Lookout domain (Beakhouse 1988; Breaks and Moore 1992, p.836), between the Gullwing–Tot lakes pegmatite group southwest to the Temple Bay Nb>Ta pegmatite near Eagle Lake (Figure 39.7). Although the rare-element pegmatites of the Dryden field have previously been described in detail (Breaks 1989; Breaks and Janes 1991; Breaks and Moore 1992), the present survey establishes a newly recognized wide distribution of metasedimentary-hosted, rare-element pegmatite mineralization within the Minnitaki–Warclub and Abram metasedimentary groups of Blackburn et al. (1991). These host rocks have likely been subjected to minimal exploration interest as prior work has mainly focussed upon rare-element deposits contained within mafic metavolcanic host rocks in the Mavis Lake and Gullwing Lake areas. The presence of anomalous tantalum values between 35 and 150 ppm in pegmatites of this metasedimentary context has established a new and extensive exploration area for tantalum.

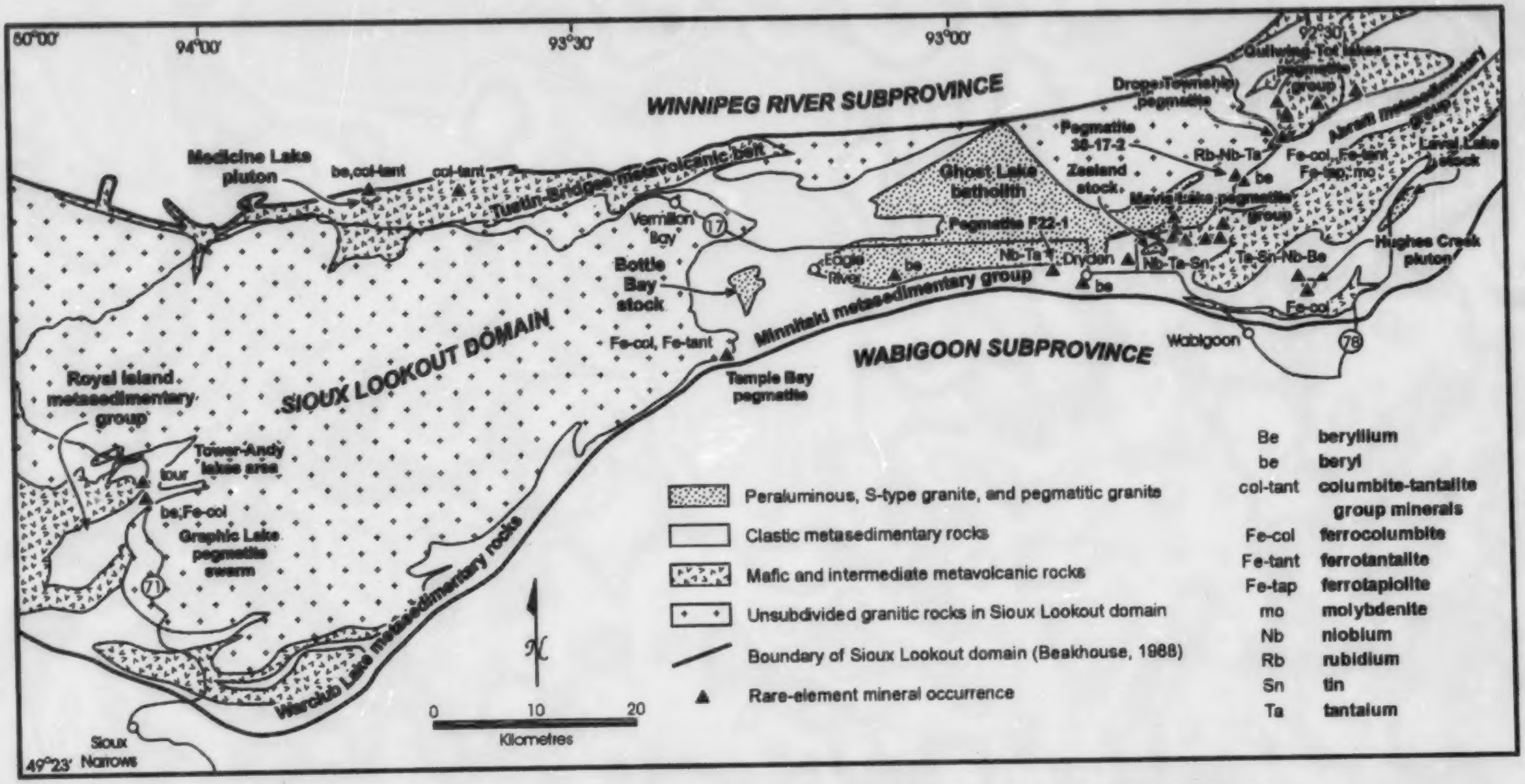
50°00'
94°00'
93°30'
93°00'
92°30'
49°23'
WINNIPEG RIVER SUBPROVINCE
WABIGOON SUBPROVINCE
SIOUX LOOKOUT DOMAIN
Medicine Lake pluton
be,col-tant
col-tant
Tustin-Bridges metavolcanic belt
Vermilion Bay
17
Bottle Bay stock
Fe-col, Fe-tant
Temple Bay pegmatite
Minnitaki metasedimentary group
Eagle River
be
Ghost Lake batholith
Pegmatite F22-1
Nb-Ta
Dryden
be
Pegmatite 38-17-2
Zealand stock
Rb-Nb-Ta
Mavis Lake pegmatite group
Nb-Ta-Sn
Ta-Sn-Nb-Be
Drope Township pegmatite
Gullwing-Tot lakes pegmatite group
Abram metasedimentary group
Fe-col, Fe-tant
Fe-tap, mo
Laval Lake stock
Hughes Creek pluton
Fe-col
Wabigoon
78
Royal Island metasedimentary group
Tower-Andy lakes area
tour
be,Fe-col
Graphic Lake pegmatite swarm
71
Warclub Lake metasedimentary rocks
Sioux Narrows
N
0
10
20
Kilometres
Peraluminous, S-type granite, and pegmatitic granite
Clastic metasedimentary rocks
Mafic and intermediate metavolcanic rocks
Unsubdivided granitic rocks in Sioux Lookout domain
Boundary of Sioux Lookout domain (Beakhouse, 1988)
Rare-element mineral occurrence
Be beryllium
be beryl
col-tant columbite-tantalite group minerals
Fe-col ferrocolumbite
Fe-tant ferrotantalite
Fe-tap ferrotapiolite
mo molybdenite
Nb niobium
Rb rubidium
Sn tin
Ta tantalum

Figure 39.7. Rare-element pegmatite mineralization and peraluminous granite masses hosted in metasedimentary rocks of the Sioux Lookout domain.

Metasedimentary-Hosted Rare-Element Pegmatite Mineralization in Abram, Minnitaki, Warclub and Royal Island Groups

Seven rare-element pegmatite localities occur within 4 metasedimentary groups of the Sioux Lookout domain (*see* Figure 39.7): Abram, Minnitaki, Warclub and Royal Island groups (Blackburn et al. 1991).

DROPE TOWNSHIP COLUMBITE-MOLYBDENITE PEGMATITE

This 2 m thick, green muscovite-rich, pegmatite dike was discovered by Breaks (1989, p.161) and is situated within the southwestern part of the Abram group. The pegmatite is white on weathered surface and emplaced concordant to foliation in the andalusite-muscovite metapelitic rocks. The dike occurs as asymmetric boudins with quartz filling at the boudin "necks" due to deformation. Black oxide minerals occur sporadically in the pegmatite as subhedral grains up to 7 by 8 mm and are associated with green muscovite, quartz, garnet and plagioclase. Molybdenite is also sparsely present as plates up to 4 mm in diameter.

The oxide mineral grains contain an average Ta_2O_5 content of 34.34% and range of 18.77 to 55.49% Ta_2O_5, which was determined from 11 electron microprobe analyses. A strong iron-rich fractionation trend (Figure 39.10) is marked by transition from dominant ferrocolumbite compositions into ferrotantalite and ultimately ferrotapiolite (mean of 4 analyses = 76.23% Ta_2O_5).

SOUTHWESTERN ZEALAND TOWNSHIP DIKE

A 30 cm thick, light pink, garnet-tourmaline-muscovite pegmatite dike occurs in Concession VII, Lot 20 of southwestern Zealand Township (UTM co-ordinates: 517330E, 5501610N; Zone15), where it is hosted by mafic-rich metawacke interbedded with lean banded iron formation of the Minnitaki group. Analysis of a grab sample from one of several narrow pegmatite dikes gave the following results: 115 ppm Ta, 150 ppm Nb, 55 ppm Sn, 30 ppm Be, 20 ppm Li, 300 ppm Rb and 5 ppm Cs.

BERYL-MUSCOVITE-TOURMALINE PEGMATITE DIKES, CENTRAL BROWNRIDGE TOWNSHIP

Numerous black tourmaline-bearing pegmatite dikes occur within a recently logged area near and along the Ghost Lake road. These dikes are hosted in metawacke and interbedded andalusite-cordierite metapelites and were recently examined by Beakhouse (this volume). At locality 01FWB-31 (UTM co-ordinates: 526704E, 5221806N, Zone 15), several green, euhedral beryl crystals, up to 4 by 6 cm in size, occur locally in a 14 m wide dike that is composed of garnet-tourmaline fine-grained leucogranite and apatite-garnet-muscovite-black tourmaline potassic pegmatite. This pegmatite represents a new rare-element occurrence in the Abram group. Preliminary results from a bulk rock sample of the tourmaline-rich, fine-grained leucogranite returned a strongly anomalous lithium concentration of 199 ppm.

Two tourmaline-rich pegmatite dikes are situated in the same area and along the Ghost Lake road about 0.5 km northeast of locality 01FWB-31. At locality 01FWB-33 (UTM co-ordinates: 527277E, 5522995N, Zone 15), an 8 m thick dike is exposed and consists of interlayered tourmaline-rich, fine-grained leucogranite and muscovite-tourmaline potassic pegmatite that are transected by narrow discordant veins, which represent a second episode of muscovite-tourmaline potassic pegmatite. The latter contain fine-grained, black, possible oxide minerals of tantalum and niobium.

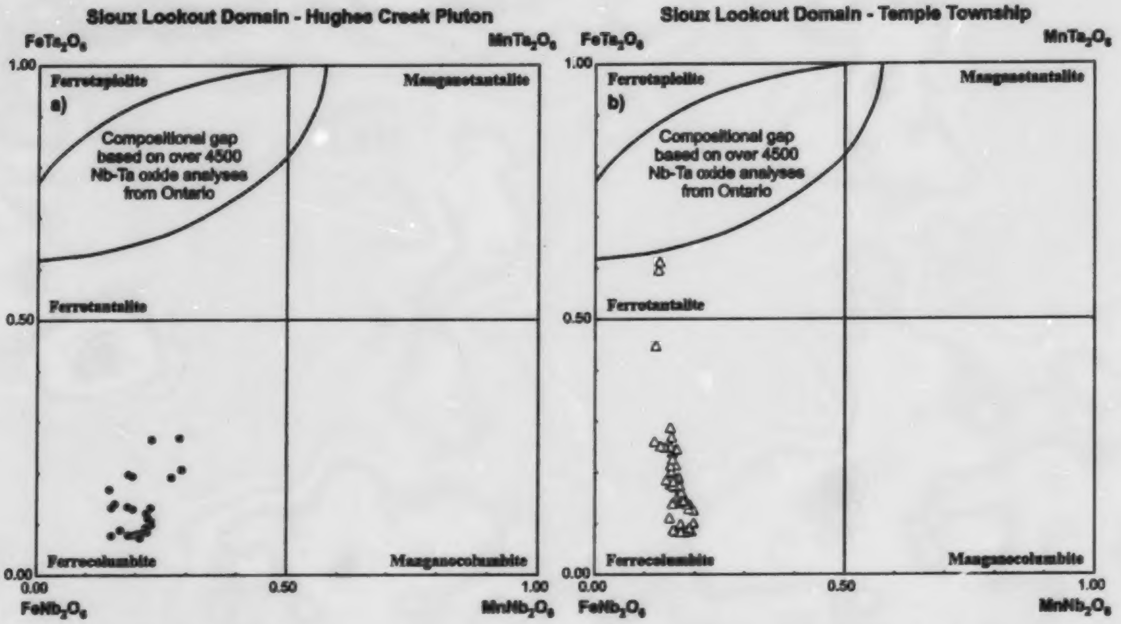

Figure 39.8. Columbite–tantalite quadrilateral plots for Hughes Creek pluton and Temple Bay (Eagle Lake) pegmatite.

At locality 30-17-2 of Breaks (1989, p.538-540), situated on the east side of the Ghost Lake road (*see* Figure 39.7) near locality 01FWB-33, a 10 m thick, layered aplite-tourmaline pegmatite dike is also hosted in metasedimentary rock. One bulk rock analysis revealed anomalous levels of the following rare-elements: 1470 ppm Rb, 110 ppm Nb, 88 ppm Sn and 50 ppm Ta.

NORTHWEST HARTMAN TOWNSHIP TANTALUM-TIN-NIOBIUM-BERYLLIUM PEGMATITE

A 15 cm thick pegmatite dike, emplaced in garnet-bearing metawacke of the Minnitaki group, was discovered by Berger (1990, p.71), who reported analyses of 152 ppm Ta, 115 ppm Sn, 74 ppm Nb, and 65 ppm Be. The low Nb/Ta ratio of 0.49 indicates strong fractionation of Ta relative to the upper continental crust ratio of 11.4 (Taylor and McLennan 1985), therefore, the area warrants exploration for additional, tantalum mineralized pegmatite dikes.

HUGHES CREEK PLUTON

This 1.3 km circular pluton (*see* Figure 39.7), which was delineated by Berger (1990), consists of tourmaline-biotite-muscovite-bearing, pegmatitic granite units and related fine-to medium-grained biotite granite. The discovery of ferrocolumbite by this survey, in the southern part of the pluton at locality 01FWB-35 (UTM co-ordinates: 534442E, 5513244N, Zone 15), confirms this pluton as a fertile granite. The pluton is a plausible source of the northwest Hartman Township tantalum-tin-niobium-beryllium pegmatite, situated 1.3 km northwest of the pluton. The fertile status of the pluton is also corroborated by a lithium value of 86 ppm in biotite-garnet-muscovite potassic pegmatite from locality 01FWB-35.

Electron microprobe analysis of a 3 by 5 mm ferrocolumbite grain indicates modest fractionation along an iron-rich trend (*see* Figure 39.8). An average Ta_2O_5 content of 15.29% within a range of 9.20 to 30.43% Ta_2O_5 was determined by 28 electron microprobe analyses.

TEMPLE BAY (EAGLE LAKE) TANTALUM-NIOBIUM PEGMATITE

A 75 by 600 m, tantalum-niobium-bearing pegmatite, hosted in metawacke of the Minnitaki group, was discovered by F. Plomp in 1997 (Plomp 1998). Grab samples collected by F. Plomp returned up to 182 ppm Ta and 553 ppm Rb. At locality 01FWB-118 (UTM co-ordinates: 477953E, 5507219N, Zone 15), a 20 m wide section of the pegmatite was observed to be concordant to foliation in the host metawacke. Most of the dike comprises biotite<<garnet-muscovite potassic pegmatite that locally grades into medium-grained, garnet-muscovite granite and quartz-rich patches in contact with blocky potassium feldspar (up to 20 by 25 cm). Local plumose aggregates of muscovite-quartz, up to 5 by 10 cm, occur in the potassic pegmatite. Black, fine-grained, possible oxide minerals occur locally in muscovite potassic pegmatite pods contained in the medium-grained garnet-muscovite granite. Four bulk rock analyses revealed 8 to 93 ppm Ta, 33 to 130 ppm Nb, 130 to 1297 Rb, 11 to 65 ppm Cs and 22 to 68 ppm Li. Nb/Ta ratios vary from 1.38 to 4.14 and reveal significant fractionation between tantalum and niobium relative to the average upper continental crust ratio of 11.4 (Taylor and McLennan 1985).

Electron microprobe analyses of oxide mineral grains (46 analyses) has confirmed ferrocolumbite and ferrotantalite compositions that define a strong, iron-suite, fractionation trend (*see* Figure 39.8). This trend is marked by a range of Ta_2O_5 contents between 10.21 to 59.23% and a mean content of 21.52% Ta_2O_5, as defined by 46 electron microprobe analyses.

GRAPHIC–TOWER LAKES AREA

Rare-element mineralization was first discovered in this area (*see* Figure 39.7) by Trowell, Logothetis and Caldwell (1982) who documented beryl-bearing, muscovite pegmatites near Graphic Lake. Trowell (1986) noted a particular abundance of tourmaline-quartz-rich veins in the Dogtooth and Gibi metavolcanic sequence, especially in the Tower Lake area. Such veins were examined for gold (Trowell 1986), which was found to be negligible, however, the possibility of a genetic connection with rare-element-bearing, peraluminous granite masses was not previously considered.

The beryl-bearing pegmatites are hosted in the Royal Island group metasedimentary rocks that are possibly correlative with nearby Warclub metasedimentary rocks (Blackburn et al. 1991). The pegmatites comprise a swarm with a breadth of least 300 m as delineated northward along Highway 71 from Graphic Lake. The strike length of the swarm has not been determined, although mapping by Trowell (1986) suggests at least 5.5 km. At Graphic Lake, dikes, between 20 cm and 8 m in width, are mainly controlled by the foliation of host rocks (metawacke of medium metamorphic grade). These dikes are massive, white, garnet-muscovite potassic pegmatite with subordinate sodic aplite and medium-grained garnet-muscovite granite. Muscovite is quite common and is typically lime green. The beryl is subtly apparent as sparse, faint green crystals up to 2 by 4 cm. Local black grains of ferrocolumbite were documented in the mid-part of the largest dike on Graphic Lake and specifically within a quartz-rich pod that also contains blue-grey, blocky potassium feldspar crystals up to 25 cm in diameter. An average of 9.56% Ta_2O_5 was determined from 20 electron microprobe analyses of the ferrocolumbite grains (Figure 39.9). Bulk analysis of 4 potassium feldspar samples indicates levels of Rb (mean = 1707 ppm; range 1695 to 2002 ppm) and Cs (mean = 38; range 35 to 42 ppm) that are typical for beryl-type rare-element pegmatites.

Black tourmaline-quartz-rich veins, 1 to 5 cm in thickness, are widespread in the Gibi and Dogtooth metavolcanic sequence and in intercalated ultramafic rocks of unknown origin. These veins are exposed over a 5 km interval along Highway 71 between Tower and Andy lakes. The tourmaline veins possibly developed as a late, boron-silica fluid phase that was related to grey, massive, medium to coarse-grained, hololeucocratic granitic dikes, 10 cm to 3 m in width. Vein contacts are commonly characterized by

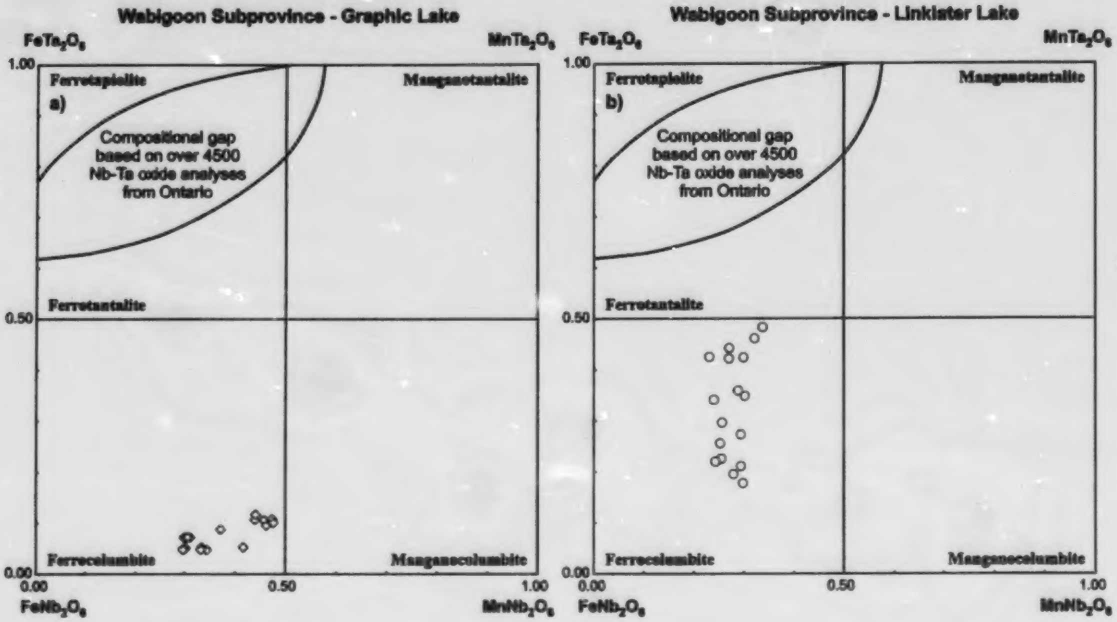

Figure 39.9. Columbite–tantalite quadrilateral plots for Graphic Lake beryl-type pegmatite and Linklater Lake beryl-cassiterite pegmatites.

biotite-rich metasomatic mineral assemblages. The veins are relatively late and, locally, transect the granite where attendant bleached zones (possible albitization) are evident. Schistose fine- to medium-grained meta-ultramafic rocks proximal to these veins also contain relatively high amounts of biotite and lesser tourmaline porphyroblasts. Several samples of the biotite- and tourmaline-rich metasomatic assemblages (termed "glimmerite"), adjacent to such veins, were submitted for bulk analysis to be analyzed for rare element content.

MISCELLANEOUS PEGMATITE DIKES IN MINNITAKI GROUP METASEDIMENTARY ROCKS

Modestly evolved, tourmaline-muscovite pegmatite dikes occur in clastic metasedimentary rocks proximal to the Zealand stock and the southern contact of the Ghost Lake batholith (*see* Figure 39.7). Potassium feldspar compositions (*see also* Breaks 1989, Figure 38 and p.553 that contain localities F22-1, F22-2, F24-3, F26-4 and F30-1) reveal anomalous levels of Rb (1370 to 1890 ppm) and Cs (50 to 84 ppm). Analyses of muscovite from the same area (*see also* Breaks 1989, Figure 38 and p.576) indicate anomalous Li (up to 1080 ppm), Rb (1370 to 2450 ppm) and Ta (30 to 60 ppm). Petrochemical data from pegmatite F22-1 (*see* Figure 39.7) reveal anomalous Li (255 ppm), Cs (120 ppm), Rb (450 ppm), Ta (35 ppm), Nb (35 ppm) and Sn (33 ppm). Such pegmatite dikes should be explored for rare metals.

LAVAL LAKE PLUTON

This 1.5 by 8 km stock (*see* Figure 39.7) was mapped by Berger (1990). A mixture of light pink (weathered surface) garnet-biotite pegmatitic leucogranite, medium-grained biotite granite and white weathering, muscovite-bearing pegmatitic granites were observed by the authors. The latter comprise muscovite fine-grained leucogranite intruded by garnet-muscovite potassic pegmatite. The muscovite potassic pegmatite units reveal slightly anomalous lithium (32 to 58 ppm) as at locality 01FWB-45 on Highway 71 (UTM co-ordinates: 541959E, 5520249N, Zone 15). The light pink biotite granite and garnet-biotite pegmatitic leucogranite units generally contain lower lithium contents (24 to 39 ppm), but overlap with the lithium range for muscovite-bearing, pegmatitic granite units.

Mineral Exploration Potential

Rare-element pegmatites of the beryl-type that contain interesting tantalum levels (30 to 150 ppm), are widely distributed in metasedimentary rocks of the Abram, Minnitaki, Warclub and Royal Island groups within the Sioux Lookout domain. Areas such as Graphic Lake require careful exploration to determine if there is a regional zonation toward lithium-rich pegmatite types. The pegmatite dike swarm in the Graphic Lake area should be examined along strike to the northeast and southwest. Exploration is warranted across the Minnitaki group in the Eagle Lake–Dryden–Hartman Township area since economically interesting tantalum levels occur in pegmatite dikes. Exploration should initially focus in the exocontact zones around fertile, peraluminous, parent granite masses such as the Hughes Creek pluton, Zealand stock and east to northeast of the Ghost Lake batholith. Exploration on strike with the Temple Bay pegmatite and to the southwest into the correlative Warclub metasedimentary group is also recommended.

Metavolcanic-Hosted Rare-Element Mineralization in the Sioux Lookout Domain

DRYDEN PEGMATITE FIELD

Rare-element pegmatite mineralization and related peraluminous granite masses have been examined in detail by Breaks (1989), Breaks and Janes (1991) and Breaks and Moore (1992). Rock samples in the OGS archive, however, were extensively analyzed by electron microprobe and the descriptions below will mainly focus upon the observed variation in chemistry of columbite-tantalite group minerals (Figure 39.10).

Mavis Lake Pegmatite Group

Columbite-tantalite compositions from this pegmatite group (*see* Figure 39.10) generally fall into the manganese-rich suite of Tindle and Breaks (1998). At the Sanmine property, currently held by Houston Lake Mining Limited, columbite-tantalite has an average Ta_2O_5 content of 32.23% within a range of 12.33 to 68.33% based upon 84 electron microprobe analyses. Appreciable ranges in Mn/(Mn+Fe) (0.230 to 0.868) and Ta/(Ta+Nb) (0.101 to 0.753) are notable. At the adjacent Fairservice property, average Ta_2O_5 contents in columbite-tantalite from most of the rare-element pegmatite dikes (total of 221 electron microprobe analyses) on the property are listed below (locations and numbering after Breaks 1989):

Pegmatite 1:	51.99%
Pegmatite 6:	57.77%
Pegmatite 9:	25.01%
Pegmatite 11:	40.38%
Pegmatite 15:	67.00%
Pegmatite 16:	60.48%
Pegmatite 18:	20.38%
Pegmatite between 14 and 18:	46.95%

Wodginite ($MnSnTa_2O_8$) was also discovered in Pegmatites 1, 6, and in Pegmatite between 14 and 18, hence, the Fairservice property becomes the third rare-element pegmatite area of Ontario to host this mineral.

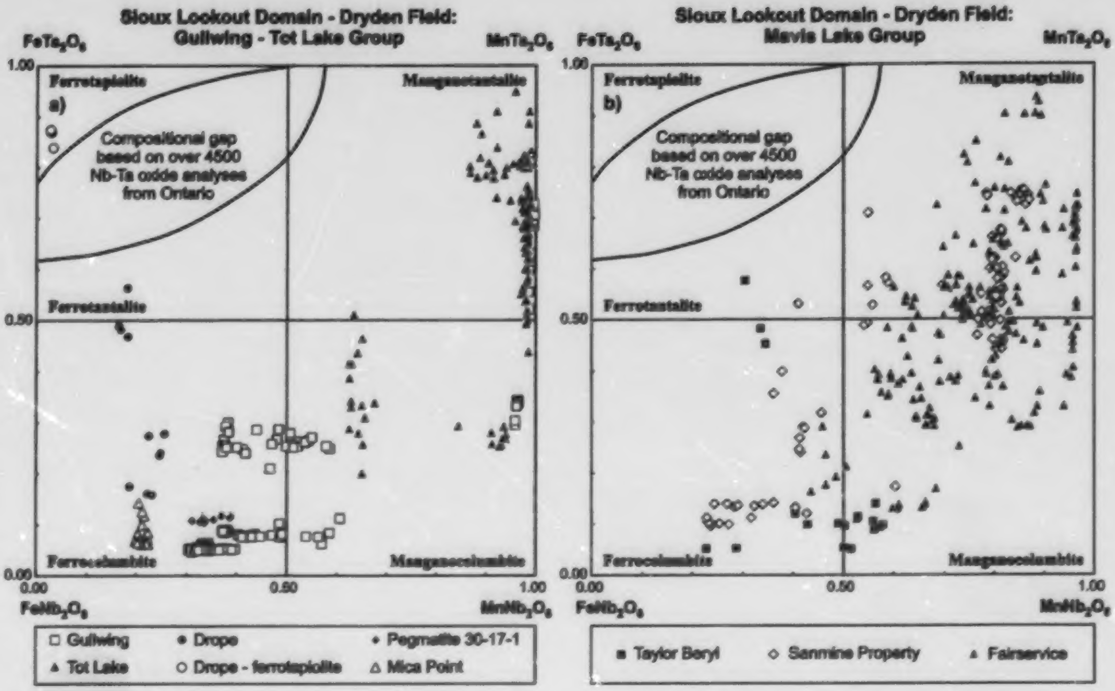

Figure 39.10. Columbite–tantalite quadrilateral plots for Gullwing–Tot lakes and Mavis Lake pegmatite groups of Dryden pegmatite field.

Gullwing–Tot Lakes Pegmatite Group

This pegmatite group also reveals a trend towards very highly evolved columbite-tantalite group compositions, but even more extreme than the Mavis Lake group (*see* Figure 39.10). Of importance are the extreme manganotantalite compositions detected in the Tot Lake pegmatite, currently being explored by Platinova Resources Limited. An average of 62.23% Ta_2O_5 and a range of 31.23 to 82.35% Ta_2O_5 was established from 142 electron microprobe analyses. Notable is the trend toward extreme Mn/(Mn+Fe) ratios (range: 0.625 to 0.990). Other pegmatites, such as the Gullwing Lake spodumene dike (average $Ta_2O_5 = 14.20\%$) and the Mica Point columbite dike (average $Ta_2O_5 = 9.09\%$), generally have more primitive compositions mainly in the ferrocolumbite field. However, late-stage albitization has resulted in more evolved compositions in the manganocolumbite and manganotantalite fields with appreciably more Ta_2O_5 (61.00%) and extremely high Mn/(Mn+Fe) ratios (0.990 to 0.998).

MEDICINE LAKE PEGMATITIC GRANITE

This 0.5 by 1.5 km ovoid mass is situated near the English River–Wabigoon subprovincial boundary zone (*see* Figure 39.7) and was first delineated by Pryslak (1976). The pluton consists of an array of internal pegmatitic granite rock types that are contained in most fertile granite plutons of the Superior Province. These include biotite-muscovite potassic pegmatite and pegmatitic leucogranite; garnet-muscovite fine-grained leucogranite, and quartz-rich patches with coarse black tourmaline and sporadic light green beryl.

Beryl was initially discovered at this location by E. Sobiski in 1949 and the property was subsequently explored as a beryllium prospect (Pryslak 1976, p.40). Columbite-tantalite was first recognized by Chisholm (1950) near the northern contact of the pluton and immediately east of the Gordon Lake road. Pryslak (1976, p.41) reported further occurrences of columbite-tantalite in the pluton. Black oxide minerals, recognized by the authors, are specifically associated with areas of albite-rich replacement patches and veins hosted by large blocky potassium feldspar crystals up to 35 by 55 cm in size. The albitized potassium feldspar megacrysts, which contain 1 to 3% black oxide minerals, specifically occur within and proximal to large quartz-rich patches. The oxide minerals are commonly less than 5 mm in diameter, however, a coarse, euhedral crystal (5 by 20 mm in size) was noted to be completely isolated in the quartz-rich patch.

Two bulk rock samples of garnet-muscovite fine-grained leucogranite were selected from old trenches 30 m east of the Gordon Lake road (UTM co-ordinates: 444464E, 5523719N, Zone 15) and revealed modest enrichment in lithium (56 and 71 ppm) and rubidium (465 to 539 ppm).

Bulk analyses of 4 potassium feldspar samples indicates modest chemical fractionation that is comparable to the northern part of the Separation Rapids pluton (Breaks and Tindle, in press: Cs (mean = 30 ppm; range = 14 to 61 ppm); Li (mean = 35 ppm; range = 28 to 44 ppm) and Rb (mean = 1776 ppm; range = 1465 ppm to 2197 ppm). K/Rb ratios (mean = 5.6, range = 4.3 to 6.6) are comparable to highly fractionated parts of the Separation Rapids pluton (Breaks and Tindle, in press).

Mineral Exploration Potential

The occurrence of columbite-tantalite oxide minerals associated with albite-rich replacement processes within the Medicine Lake pluton indicates that pegmatitic granites of this pluton, and possibly those in the Tustin–Bridges greenstone belt, should be explored for similar associations. More extensive albite-rich replacement within such pegmatitic granites or derivative exocontact pegmatite dikes could harbour economically interesting tantalum mineralization. Furthermore, pegmatite swarms potentially derived from pegmatitic granite plutons, such as at Medicine Lake, should be examined for lithium-rich mineralization that could have been overlooked due to the presence of petalite or white spodumene.

WABIGOON–ENGLISH RIVER SUBPROVINCIAL BOUNDARY ZONE

This boundary zone has rare-element mineralization distributed over a 130 km strike length between Linklater Lake east to Superb Lake near Nakina. The rare-element mineralization in this region has not been investigated in detail since the 1950s with the exception of the Superb Lake spodumene pegmatite (Stott and Parker1997).

Linklater Lake Columbite-Beryl-Tourmaline-Cassiterite Pegmatites

Cassiterite-bearing pegmatites were discovered near the southeastern end of Linklater Lake (Figure 39.11) in 1941 by prospector Stan Johnson (Chisholm 1948). The 15 by 500 m area was extensively examined for tin mineralization in 1948 by San Antonio Gold Mines Limited who reported grades up to 1.83 % Sn in a channel sample across 15 cm (Chisholm 1948, p.3). However, the tantalum potential of the area had not been given adequate consideration until recent work by O'Reilly (2000).

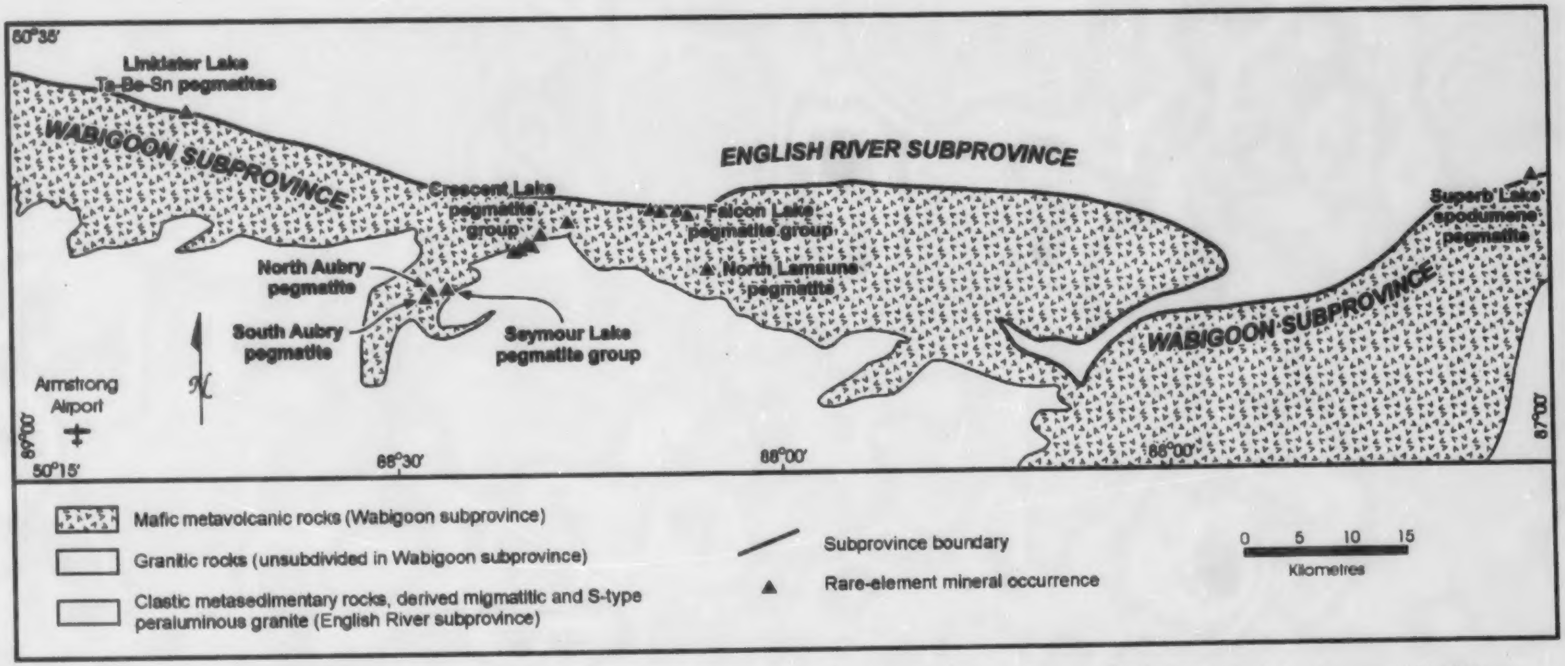
50°35'
Linklater Lake
Ta-Be-Sn pegmatites
WABIGOON SUBPROVINCE
ENGLISH RIVER SUBPROVINCE
Crescent Lake pegmatite group
Falcon Lake pegmatite group
North Lamaune pegmatite
North Aubry pegmatite
South Aubry pegmatite
Seymour Lake pegmatite group
Superb Lake spodumene pegmatite
WABIGOON SUBPROVINCE
N
Armstrong Airport
89°00'
50°15'
88°30'
88°00'
86°00'
87°00'
Mafic metavolcanic rocks (Wabigoon subprovince)
Granitic rocks (unsubdivided in Wabigoon subprovince)
Clastic metasedimentary rocks, derived migmatitic and S-type peraluminous granite (English River subprovince)
Subprovince boundary
Rare-element mineral occurrence
0
5
10
15
Kilometres

Figure 39.11. General geological location of rare-element mineralization situated in the English River–Wabigoon subprovincial boundary zone in the Armstrong–Nakina area (geology generalized *after* Parker and Stott 1988).

An extensive swarm of light to deep pink, tourmaline-muscovite pegmatite dikes are concordant to intensely foliated and sheared metawacke rocks. The host rocks form part of an extensive metasedimentary unit that is traceable for about 40 km, from Rove Lake east to Ratte Lake, and varies between 0.6 and 1 km in width. This unit has been incorrectly mapped as "quartzite" by Gussow (1940). The pegmatites are 0.2 to 1 m thick; are variably sheared and boudinaged; and typically exhibit a protomylonite texture marked by augen of potassium feldspar and plagioclase up to 2.5 by 4 cm and lenses of grey quartz up to 1 to 2 mm by 5 cm.

Accessory phases in the pegmatite include garnet, fluorapatite, alluaudite [$NaCaFe^{2+}(Mn^{2+}, Fe^{2+}, Fe^{3+}, Mg)_2 (PO_4)_3$] and black tourmaline of the schorl-dravite group. Cassiterite is dark brown, generally fine grained and inconspicuous. Contents of Ta_2O_5 in the cassiterite vary from 0.34 to 0.79%, which is low relative to cassiterite from the Separation Rapids pegmatite group (up to 11% Ta_2O_5: Tindle and Breaks 2000).

Bulk rock analytical data received to date reveal anomalous beryllium (66 to 250 ppm) and suggest small amounts of fine-grained beryl that were not observed in the field. Lithium contents in the tourmaline-muscovite pegmatite are low (4 to 15 ppm), but an anomalous value of 120 ppm Li was documented in a 1 cm thick biotite-rich metasomatic selvage that occurs along the pegmatite contact. These data support classification of the pegmatites as beryl-type.

Limited electron microprobe work of 17 analyses confirm the presence of ferrocolumbite (*see* Figure 39.9) that exhibits a range of Ta/(Nb+Ta) ratios (0.177 to 0.483) and is indicative of the iron suite (Tindle and Breaks 1998). Mean content and range of Ta_2O_5 in the ferrocolumbite is 34.72% and 20.51 to 46.02%, respectively.

MINERAL EXPLORATION POTENTIAL

The metawacke—meta-arkose metasedimentary rocks of the Linklater Lake area, are widely distributed along the English River–Wabigoon subprovincial boundary, which represents the only known host for the cassiterite-bearing pegmatites in the area. Geological mapping was conducted only in the western part of this unit (Sutcliffe 1988). The area east of Hollingsworth Lake has not received detailed coverage since the work of Gussow (1940). Further examination of this metasedimentary host is warranted for additional occurrences of beryl-type pegmatites that could contain tantalum- and tin-bearing oxide minerals.

Seymour Lake Pegmatite Group

This pegmatite group (*see* Figure 39.11), with a minimum extent of 0.8 by 1.8 km, comprises 3 known spodumene pegmatites called the North Aubry, South Aubry and Seymour pegmatites (Pye 1968, p.47-49). Such pegmatites were previously evaluated for lithium in the 1950s by The Anaconda Company (Canada) Limited, however, their potential for tantalum has only been examined recently. Linear Resources Limited conducted trenching (8 trenches that totals 330 m) and extensive channel sampling of the North and South Aubry pegmatites.

NORTH AND SOUTH AUBRY PEGMATITES

Two large pegmatite dikes of the albite-spodumene type (Černý 1989) are situated 2.7 km west of Seymour Lake along a prominent ridge that has approximately 100 m of local relief. Recent exploration for tantalum by Linear Resources Limited has exposed the North Aubry pegmatite in 5 trenches over

265 m and the South Aubry pegmatite in 3 trenches over 120 m. Trench numbering, referred to in this report, follows that of Linear Resources Limited.

The North Aubry pegmatite varies from 15 to 75 m in width and is at least 265 m in strike length. The South Aubry pegmatite, situated 800 m to the south, is at least 120 m in strike length with a width of up to 50 m as exposed in 3 trenches. The highest tantalum values found by this company occur in Trench 5 of the North Aubry pegmatite where 15 samples ranged from 0.029 to 5.7% Ta_2O_5. An average of 2.39% Ta_2O_5 was obtained from 4 successive channel samples of 1 m each near the eastern end of Trench NA-5 (Linear Resources Limited, News Release, July 3, 2001). Further results from other trenches (Linear Resources Limited, News Release, July 16, 2001) include 0.036% Ta_2O_5 across 5.7 m in Trench NA-4; 0.027% Ta_2O_5 across 5.1 m in Trench NA-3; 0.42% Ta_2O_5 across 2 m in Trench NA-4; and 0.026% Ta_2O_5 across 17.6 m in Trench NA-2. The South Aubry pegmatite has also been extensively channel sampled by Linear Resources Limited who reported Ta_2O_5 contents up to 0.028% over 1 m. Most of the North Aubry pegmatite exhibits little internal zonation, which is typical of pegmatites of the albite-spodumene-type (Černý 1989). The main unit consists of a coarse muscovite-green spodumene-quartz-potassium feldspar-cleavelandite assemblage augmented by layers and irregular masses of primary aplite, quartz-rich patches and sparse muscovite-rich, greisen-like pods. Randomly oriented, coarse green spodumene, up to 35 by 35 cm in basal sections and 20 cm by 1.6 m parallel to the long dimension, comprise 30 to 40% of the main pegmatite unit.

Accessory minerals in the pegmatite include light green, white and scarce light pink beryl up to 15 by 17 cm in basal sections, manganocolumbite, manganotantalite, lepidolite, and sparse black tourmaline, garnet, ferrocolumbite, microlite, ferrotapiolite and zircon.

Primary sodic aplite occurs in pods, up to 60 cm by 1 m, and in layers within the spodumene-rich pegmatite that are up to 1 m thick and at least 6 m in length. This unit mainly consists of sugary quartz and albite with minor blue apatite and muscovite. Near the eastern end of Trench NA-2, primary aplite pods are enveloped in a quartz-rich mass with notable concentrations of black, manganotantalite along the contact between the aplite and quartz-rich masses.

Quartz-rich masses consist of 70 to 80% grey quartz and typically contain the coarsest blocky potassium feldspar crystals (up to 95 cm by 2.5 m). Petrographic evidence suggests the following sequence of mineral crystallization: apatite, early quartz, early oxide → spodumene → potassium feldspar, albite → beryl → late oxide → late quartz.

Miarolitic cavities, up to 5 by 6 cm in size, occur in cleavelandite-rich aplite of Trenches NA-4 and NA-5 and are mainly lined with cleavelandite crystals with minor muscovite and tourmaline, all of which are coated by a drusy film of hematite.

Field and chemical evidence indicates that the most chemically evolved part of the North Aubry pegmatite is situated in Trench NA-5, where high Ta_2O_5 values were obtained in the channel samples of Linear Resources Limited. The electron microprobe results (180 analyses) confirm these high bulk rock Ta_2O_5 levels as an average of 80.7% Ta_2O_5 (maximum = 84.9%) was attained on samples from Trench NA-5. The data from Trench NA-5 represent the most tantalum-rich manganotantalite documented to date in Ontario. Average Ta_2O_5 contents in columbite-tantalite group minerals for Trenches NA-1 to NA-4, listed below, were somewhat lower, but still significant in terms of the potential delineation of economic tantalum mineralization. The analyses collectively reveal a strong manganese-suite trend for the North Aubry pegmatite (Figure 39.12).

- Trench NA-1: 58.7% Ta_2O_5
- Trench NA-2: 49.2% Ta_2O_5
- Trench NA-4: 50.7 % Ta_2O_5

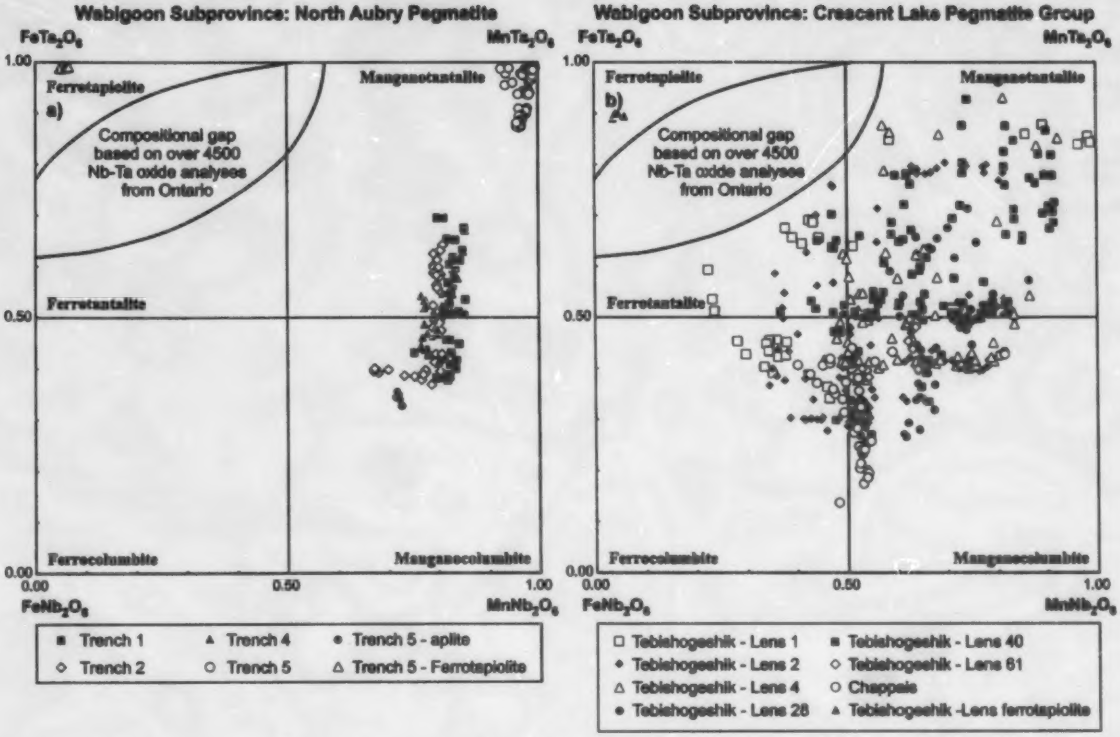

Figure 39.12. Columbite–tantalite quadrilateral plot for North Aubry pegmatite(Seymour Lake pegmatite group) and various lithium pegmatites of the Crescent Lake group.

The most spectacular manganotantalite mineralization was encountered in Trench NA-5. The North Aubry pegmatite is partly exposed in this trench as erosional remnants of flat-lying thin sheets that strike 155° with a dip of 15° southwest. At the east end of this trench, the pegmatite is zoned, marked by an outer zone that is a 60 cm thick sodic aplite unit composed of quartz, cleavelandite and sparse, platy black oxide grains. The aplite symmetrically envelops a core zone of muscovite-pink beryl-potassium feldspar-spodumene-quartz-cleavelandite pegmatite that is at least 3.5 m thick. In the west part of the trench, the flat-lying sheets are connected with subvertical aplite dikes suggesting that a "stacked" pegmatite-aplite emplacement system is present, therefore, more flat-lying pegmatite-aplite sheets could occur at depth.

Coarse, black, subhedral to euhedral, manganotantalite crystals, up to 3.5 by 5 cm, are amongst the largest crystals observed by the authors in northwest Ontario. These crystals occur within the interstices between coarse, randomly oriented blades of faint green to locally light pink spodumene, best described as a "box-work" texture. The manganotantalite is commonly partly or completely enveloped by white cleavelandite. The manganotantalite crystals resulted from primary magmatic crystallization since no petrographic evidence of subsolidus, replacement stage albitization could be found. Several coarse crystals of faint pink beryl occur in the spodumene pegmatite unit and reach 20 cm in basal sections. Lepidolite, as narrow books up to 2 cm wide and 10 cm in length, also occur in the spodumene pegmatite and could represent a late alteration of muscovite.

Extensive lithium metasomatism is evident in the pillowed, mafic metavolcanic host rocks near the west end of Trench NA-5. The host rocks, also with local calc-silicate segregation of epidote-quartz-carbonate, are bright blue due to high concentration of randomly oriented holmquistite needles. A channel sample of 20 cm cut across one of the holmquistite-rich pillows revealed 7519 ppm Li that indicates significant lithium metasomatism. Thus, lithium may be a potentially useful element in detecting other rare-element pegmatites by lithochemical surveys on the property and adjoining areas.

The South Aubry pegmatite, which is up to 50 m in width, largely consists of muscovite-rich potassic pegmatite, characterized by impressive ovoid symplectites of quartz-muscovite. These segregations, up to 1 m in diameter, contain approximately equal amounts of quartz and muscovite.

Green spodumene is considerably lower in abundance in the South Aubry pegmatite and is mainly confined to layers, up to 4 m thick, that also contain faint green beryl-quartz-blocky potassium feldspar and cleavelandite. Veins of the spodumene pegmatite locally transect the muscovite-rich potassic pegmatite. Platy black oxide minerals, mainly as radiating aggregates up to 1 to 6 mm by 2 cm, occur locally in the spodumene pegmatite.

MINERAL EXPLORATION

The significant bulk rock and mineral tantalum contents at the North Aubry pegmatite indicates that this pegmatite group has a high potential for tantalum deposits. Lithium lithochemistry in the host mafic metavolcanic rocks is likely to be a useful exploration tool in the delineation of further tantalum-bearing pegmatites in addition to a useful aid in the discovery of blind pegmatites.

Crescent Lake Pegmatite Group

This group consists of 8 pegmatites that are hosted in mafic metavolcanic and metatonalite rocks within a 1.2 by 6 km area (*see* Figure 39.11). The pegmatites were initially described in detail by Pye (1968, p.50, p.56-59, *see also* Figure 8) and later examined briefly by Breaks (1981). Exploration for tantalum was initially undertaken by Donner (1982) in the Tebishogeshik lenses 1 to 4, where a range in Ta_2O_5 values from 0.045% Ta_2O_5 across 8.4 m to 0.37 % Ta_2O_5 across 1 m was established in a series of continuous chip samples collected intermittently across a 700 m strike length of the pegmatite group. Platinova Resources Limited recently optioned 46 claims units that contain most of the pegmatites in the Crescent Lake group (Platinova Resources, News Release, August 15, 2001).

The pegmatites are classified as albite-spodumene type of Černý (1989, 1991), but are notable for the high tantalum content in their oxide minerals (columbite-tantalite group and microlite) coupled with evolved garnet compositions. The pegmatites exhibit simple internal zonation marked by outer zones of quartz-muscovite-cleavelandite, apparently of primary origin, that grade into central cores of blocky potassium feldspar-green spodumene-quartz, as in lenses 2 and 3. In lens 2, a 3 m thick quartz-rich core zone is traceable for 37 m on surface and contains between 18 and 42% green spodumene megacrysts. Blocky potassium feldspar, up to 20 cm diameter, is variably replaced by irregular masses of albite. Thin platy to rectangular black grains of columbite-tantalite, up to 6 by 7 mm, are disseminated in low quantities throughout these albitized areas.

Minerals of the columbite-tantalite group are widespread in pegmatites of the Crescent Lake group as indicated from 456 electron microprobe analyses amassed from 26 samples. The oxide minerals were generated both by primary magmatic crystallization and by late stage, albite-rich replacement. Spectacular oscillatory zoning marked by zones of generally increasing tantalum content is a clear indication of crystallization under magmatic conditions. Late-stage albitization is also apparent in the pegmatites of this group, subtly marked by cleavelandite-rich replacement in parts of coarse blocky potassium feldspar megacrysts as in lens 1. Black oxide grains, generally 1 mm in diameter or less, have been noted within these alteration zones.

MINERAL CHEMISTRY

An extensive electron microprobe investigation that involved 1028 analyses was undertaken on the various oxide minerals, garnet, potassium feldspar and micas. This work involved most of the pegmatites that comprise this pegmatite group: the Tebishogeshik lenses 1, 2 and 3; the Dempster lenses 28, 40, and 61; and the Chappais Lake pegmatite (Pye 1965).

A significant proportion of the electron microprobe data fall within the manganotantalite field (*see* Figure 39.12) and confirms a high degree of fractionation. Manganocolumbite, ferrotantalite, microlite and ferrocolumbite compositions have also been documented. Overall, an average of 49.95% Ta_2O_5 and range of 16.26 to 81.61% Ta_2O_5 were established from 478 electron microprobe analyses of the columbite-tantalite group. Ferrocolumbite and manganese-poor manganocolumbite represent the most primitive compositions and occur in the Chappais Lake pegmatite (33.69% Ta_2O_5), Dempster lens 61 (average 43.81% Ta_2O_5), and Tebishogeshik lens 2 (average 35.42% Ta_2O_5). With increasing pegmatite evolution, average Ta_2O_5 content in oxide minerals increases in the following order: Tebishogeshik lens 2 (46.20% Ta_2O_5); Dempster lens 28 (48.04% Ta_2O_5); Tebishogeshik lens 3 (51.76% Ta_2O_5); Dempster lens 40 (57.98% Ta_2O_5); and Tebishogeshik lens 1 (65.15% Ta_2O_5). Individual analyses of manganotantalite from lenses 3 and 4 exceed 80% Ta_2O_5 and are amongst the highest found in lithium-rich pegmatites of Ontario. The pegmatites of this group have a high potential for economic tantalum deposits.

Falcon Lake Pegmatite Group

This 0.25 by 4.5 km cluster of 7 spodumene pegmatites lies to the east of the Crescent Lake group (*see* Figure 39.11). One sample from a 3 m thick spodumene pegmatite dike within a group of 3 spodumene pegmatites near Ottertail Creek (Pye 1968, "Far West deposits", p.55-56) was examined by the electron microprobe. Oxide minerals were found to consist of manganotantalite and ferrotapiolite.

The ferrotapiolite has an average and range of 78.46 % and 76.88 to 80.58% Ta_2O_5, respectively, from 24 analyses. Furthermore, exceptionally high Rb_2O (4.5% average) and Cs_2O (4653 ppm) were determined in the potassium feldspar and are the highest values recorded to date in this mineral within Ontario. This cesium content exceeds that in limited data from Lily Pad Lake (3.2% Rb_2O; 3294 ppm Cs_2O) and the Tanco pegmatite (Černý, Ercit and Vanstone 1996: 0.02 to 0.30% Cs_2O; 0.77 to 2.93% Rb_2O). Pegmatites of this group could contain pollucite mineralization, in addition to representing a good target for tantalum.

Superb Lake Lithium Pegmatite

This pegmatite (*see* Figure 39.11) was discovered in the 1950s by unknown person(s) (Mulligan 1965, p.63) and has not been examined until recently (Stott and Parker 1997; Parker and Stott 1998). This occurrence was not visited during this study.

QUETICO SUBPROVINCE

Rare-element pegmatites exhibit widespread distribution in the Quetico Subprovince and involves at least a 540 km strike length from the Wisa Lake area east to the Lowther Township pegmatite near Hearst (Figure 39.13). Furthermore, the restriction of rare-element pegmatites to boundary zones with adjacent subprovinces is not applicable to the Quetico Subprovince. It is apparent from the compilation in Figure 39.13 that rare-element mineralization is distributed across the Quetico Subprovince and a large percentage of rare-element pegmatites are concentrated within the centre of the subprovince as, for example, at Georgia Lake (Pye 1965).

Armstrong Highway Cross-Section

Strongly peraluminous, muscovite, cordierite and garnet-bearing pegmatitic granite dikes, with local black tourmaline, were found to occur widely in the Quetico Subprovince along the Armstrong Highway between Walkingshaw Lake north to De Courcey Lake (Figure 39.13). Detailed rock sampling was undertaken along this highway and adjacent area—including the De Courcey–Eayrs lakes area—along the Quetico–Wabigoon subprovincial boundary zone, where beryl was reported by Jollife (1933) about 1.8 km northeast of Eayrs Lake. Although granites and pegmatites that contain garnet, tourmaline and muscovite were previously mapped (Kaye 1969) within this area, no mineralogical or petrochemical work has been conducted.

Rare-element mineralization was discovered by the current survey within an extensive swarm of pegmatitic granite dikes at Onion Lake near Thunder Bay. The lens-shaped dikes of this swarm, as evident in the area near the junction of Highway 527 and the Barnett Lake road, occur as northeast-striking, "whale-back" glacial erosional remnants that achieve a maximum size of 100 by 300 m. The internal units comprise

- muscovite-rich potassic pegmatite
- quartz-rich patches with blocky potassium feldspar, coarse muscovite books and sparse beryl
- fine-to medium-grained, garnet-biotite-muscovite granite
- garnet-biotite-muscovite pegmatitic leucogranite
- garnet and muscovite-garnet aplite

The quartz-rich patches locally contain light green beryl up to 1 by 16 cm, as at locality 01FWB-107 (UTM co-ordinates: 346199E, 5397916N; Zone 16). Black, possible oxide minerals, up to 3 by 3 by 5 mm, were discovered at 01JBS-52 (UTM co-ordinates: 346512E, 5398007N; Zone 16) and apparently associated with local albitization of potassium feldspar megacrysts. Blocky potassium feldspar megacrysts up to 50 cm in diameter and muscovite books up to 10 cm in thickness were noted in the potassic pegmatite and enclosed quartz-rich patches.

Dikes and foliation-concordant peraluminous granites and pegmatites were emplaced into Quetico Subprovince metasedimentary rocks during at least three intrusive episodes characterized by the following rock types:

1. grey, garnet- biotite granite, fine- to medium-grained
2. cordierite and garnet-cordierite granite
3. sheets of pegmatitic leucogranite and associated quartz-rich patches

Pegmatite sheets, at least 5 m thick, are evident on the Armstrong Highway as at locality 01FWB-105 (UTM co-ordinates: 339218E, 5416563N; Zone 16). These sheets consist of coarse-grained garnet-muscovite-cordierite granite that contain15 to 20% cordierite crystals pervasively altered to soft, dark green-black pseudomorphs. The coarse granite is gradational into muscovite-rich, miarolitic cavity-bearing, pegmatite patches (blocky potassium feldspar, muscovite, cleavelandite, quartz, an unidentified brown black mineral and green apatite). Lithium values of 41 ppm in both the cordierite granite and miarolitic pegmatite patches indicate modest fractionation of the element at about twice the upper continental crust average (Taylor and McLennan 1985).

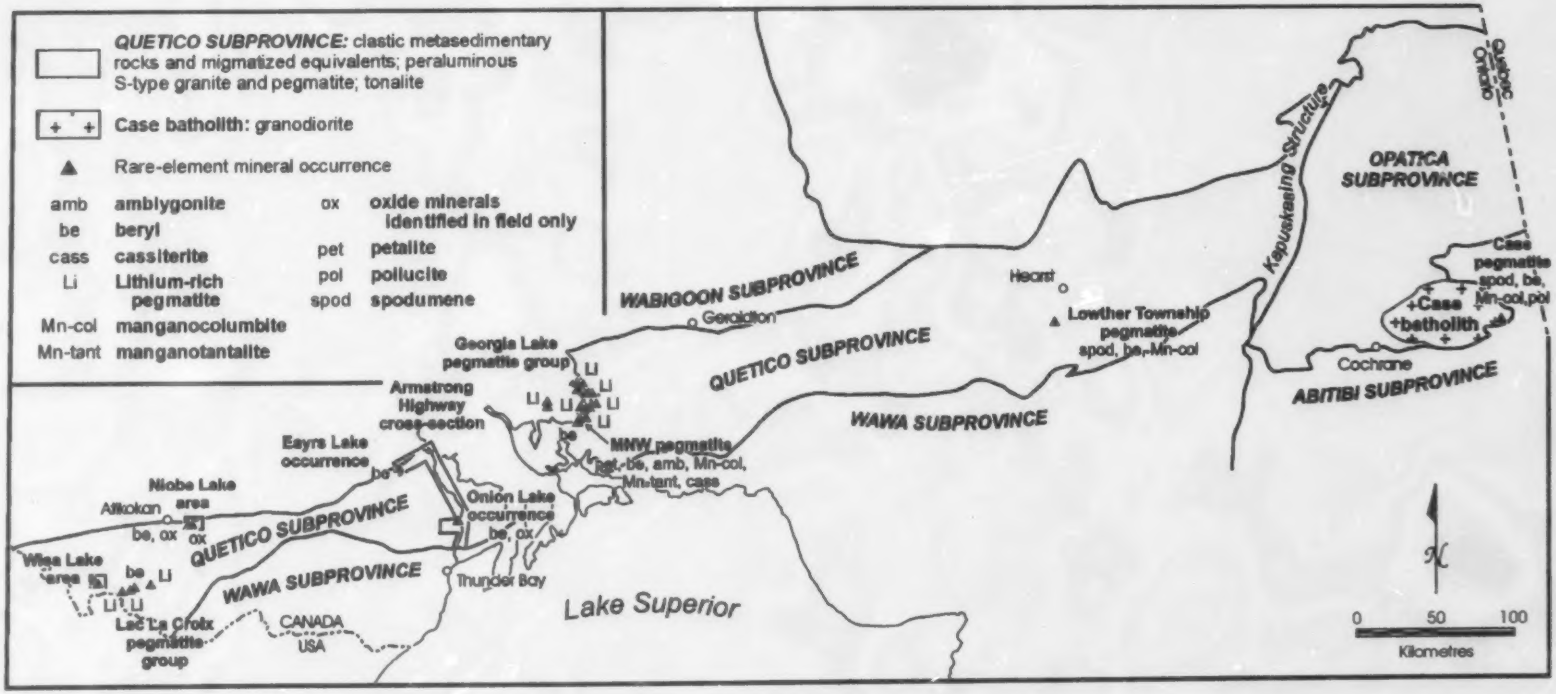
QUETICO SUBPROVINCE: clastic metasedimentary rocks and migmatized equivalents; peraluminous S-type granite and pegmatite; tonalite
Case batholith: granodiorite
Rare-element mineral occurrence
amb amblygonite
be beryl
cass cassiterite
Li Lithium-rich pegmatite
Mn-col manganocolumbite
Mn-tant manganotantalite
ox oxide minerals identified in field only
pet petalite
pol pollucite
spod spodumene
Quebec
Ontario
OPATICA SUBPROVINCE
Kapuskasing Structure
Case pegmatite spod, be, Mn-col,pol
+Case +batholith
Cochrane
ABITIBI SUBPROVINCE
Hearst
Lowther Township pegmatite spod, be, Mn-col
WABIGOON SUBPROVINCE
Geraldton
QUETICO SUBPROVINCE
WAWA SUBPROVINCE
Georgia Lake pegmatite group
Armstrong Highway cross-section
Eayrs Lake occurrence
MNW pegmatite pet, be, amb, Mn-col, Mn-tant, cass
Niobe Lake area
Atikokan
Onion Lake occurrence
be, ox
Thunder Bay
Lake Superior
Wisa Lake area
Lac La Croix pegmatite group
CANADA
USA
N
0 50 100
Kilometres

Figure 39.13. Location of metasedimentary-hosted rare-element mineralization associated with the Quetico Subprovince.

Niobe–Nym Lakes Area

Muscovite-bearing pegmatite dikes and small pegmatitic granite masses are widely exposed along Highway 11 at least between the Nym Lake road junction and west to Niobe Lake (McIlwaine and Larsen 1981a, 1981b). The area (*see* Figure 39.13) was briefly investigated by the present survey owing to anomalous rare-element levels (lithium, rubidium, gallium, cesium and tin) detected in a lake sediment survey within the general area (Jackson 2001). Previous petrochemical investigation in the area indicated the presence of modestly evolved muscovite-garnet-biotite-albite granites in the Crystal Lake area as indicated by 199 to 338 ppm Rb and a range in K/Rb ratios of 80 to 211 (Smith and Williams 1980).

Rare-element mineralization was discovered by the present survey at locality 01JBS-78 (UTM co-ordinates: 614652E, 5398381N; Zone 15) within a pegmatite-aplite dike system 0.3 to 4 m thick. Sporadic, yellow-green beryl crystals, up to 2 cm in diameter, occur in a muscovite-potassium feldspar-quartz-rich pegmatite core rimmed by garnet-muscovite aplite. Black grains of possible niobium-tantalum oxide minerals, up to 1 to 6 mm by 10 mm, occur in several parts of the pegmatite and aplite units.

Possible black niobium-tantalum minerals, up to 3 by 5 mm in size, were found in sparse quantities at localities 01JBS-79 (UTM co-ordinates: 615436E, 5398378N; Zone 15); 01JBS-80 (UTM co-ordinates: 619907E, 5399952N; Zone 15) and 01FWB-128 (UTM co-ordinates: 617482E, 5399102N; Zone 15). All of these samples are currently under electron microprobe investigation.

Lowther Pegmatite

This pegmatite, situated in the mid-part of the Quetico Subprovince near Hearst (Bennett et al. 1967), was discovered in 1939 by A. Villeneuve. It has been intermittently examined for its rare-element mineralization, but has not been previously evaluated for tantalum potential.

The Lowther pegmatite is classified as an albite-spodumene type that is significantly albitized. The main pegmatite occurs as a 1 to 2 m by 30 m mass oriented at 310°, which is approximately sub-perpendicular to the contact of its host rock, a northeast-striking, 45 m wide dike of muscovite-biotite pegmatitic granite. The pegmatitic granite dike is, in turn, hosted in a hornblende-biotite tonalite mass of unknown extent. The occurrence of a smaller pegmatite within the same pegmatitic granite dike and having a similar strike orientation suggests a “ladder vein” structure for the rare-element pegmatites.

The primary mineralogy comprises faint green spodumene, coarse muscovite books up to 5 cm in diameter, blocky potassium feldspar and faint green beryl. Irregular zones of orange garnet (presumably spessartine-rich)-green muscovite-cleavelandite-rich replacement masses are significantly present. Platy black oxide grains, mostly fine to medium grained have mostly been found in the cleavelandite-rich replacement masses. Oxide minerals recognized to date include manganocolumbite and microlite.

MINERAL CHEMISTRY

Electron microprobe investigation of the black oxide minerals (60 analyses) indicates that they are exclusively manganocolumbite (Figure 39.14) with an average Ta_2O_5 content of 26.85% and a range of 11.92 to 39.45% Ta_2O_5. The manganocolumbite, however, reveals a manganese-suite trend to highly evolved compositions in terms of the Mn/(Mn+Fe) ratio that varies between 0.661 and 0.965. Microlite occurs as patch-like domains within manganocolumbite and is interpreted to have developed during late albitization of the pegmatite.

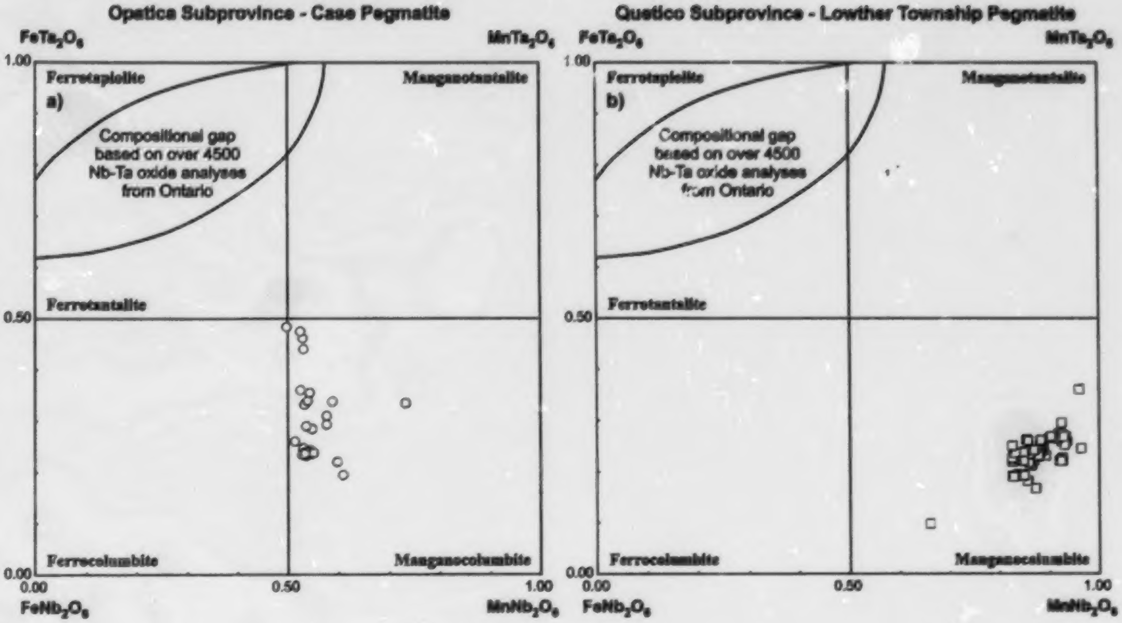

Figure 39.14. Columbite–tantalite quadrilateral plot for Case and Lowther Township spodumene pegmatites.

Bulk analytical work in a sample of coarse muscovite books gave values of 54 ppm Ta, 375 ppm Nb, 247 ppm Cs, 1155 ppm Li, and 5515 ppm Rb. Three analyses of blocky potassium feldspar revealed 82 to 305 ppm Cs and 971 to 3725 ppm Rb. Beryl contains 330 ppm Rb, 1728 ppm Li, 1.6% Na_2O and an exceptionally high Cs_2O content of 2.6%. Such a cesium level is considered highly evolved and closely compares with Cs_2O contents in beryl from the Tanco pegmatite (2.47 to 3.27% Cs_2O: Černý et al. 1981, p.114). The Lowther pegmatite and surrounding area require exploration for similar rare-element pegmatite bodies.

Wisa Lake Pegmatite Group

Two spodumene pegmatites, discovered in the 1950s, are hosted in medium-grade metasedimentary rocks in the central Quetico Subprovince of the Lac La Croix area (*see* Figure 39.13). The area was explored for lithium in 1956 by Lexindin Gold Mines Limited (Mulligan 1965, p.66) with attention directed to the largest pegmatite near Wisa Lake (UTM co-ordinates: 557141E, 5363473N; Zone 15) that was traced on surface for a strike of 335 m with widths from 6 to 12m. This pegmatite is flat lying, but may also dip 20° to the north, and consists of mildly deformed, green muscovite-potassium feldspar-spodumene-quartz-albite rock layered with blue apatite-garnet-muscovite aplite. Possible black oxide grains were noted in both rock types.

Dikes of apatite-muscovite aplite and muscovite-rich potassic pegmatite, between 35 cm and 4 m in thickness, occur sporadically on the nearby Lac La Croix road (e.g., UTM co-ordinates: 557456E, 5362364N; Zone 15). Dikes such as these should be examined closely for possible niobium-tantalum oxide minerals.

OPATICA SUBPROVINCE

Rare-element mineralization in the Opatica Subprovince is currently known only at the Case pegmatite in the Lake Abitibi area (*see* Figure 39.13). Nevertheless, this albite-spodumene-type pegmatite comprises the fifth largest lithium-rich pegmatite in the Superior Province of Ontario.

Case Pegmatite

This swarm of 3 pegmatites has witnessed intermittent exploration interest since its discovery in 1959 (Lumbers 1962, p.29). A previous investigation generally characterized the mineralogy that included columbite-tantalite and pollucite (Nickel 1963). A bulk sample of pollucite-bearing material contained 5.79% Cs_2O (Nickel 1963). Recent work (Horne 2000) involved extensive stripping over most of the exposed strike length of 290 m, followed by channel sampling and total field magnetic and magnetic gradient ground geophysical surveys. Recently Platinova Resources (Platinova Resources, News Release, August 8, 2001) optioned the property in order to assess the tantalum potential of the Case pegmatite system. An average content of 0.024% Ta_2O_5, within a range of 0.003 to 0.068%, was calculated from 16 grab samples selected by Horne (2000). Recent results from channel sampling and a limited diamond drill program established an average of 0.024% Ta_2O_5 across 8 m in the Central Dike and a range of 0.011% (over 1 m) to 0.032% Ta_2O_5 (over 7.7 m) for the North Dike (Platinova Resources, News Release, October 4, 2001).

The Case pegmatite system is hosted in the southeastern part of the Case batholith, an extensive 50 by 85 km, ovoid granitic complex that is apparently part of the Opatica Subprovince (Jackson and Fyon 1991). The immediate host rocks of the pegmatite dikes consist of massive to subtly foliated, biotite granodiorite that is characterized by biotite-rich orbicules that range in diameter from 1 to 7 cm . Such entities are classified as proto-orbicules (Leveson 1966) and commonly exhibit a linear alignment that is parallel to the weak foliation of its granodiorite host.

The pegmatite swarm, which strikes at 060 to 070° and dips 40 to 60° north, consists of 3 *en échelon* dikes exposed within a 260 by 350 m area situated immediately east of the contact between the Case batholith and Scapa metasedimentary rocks (Lumbers 1962):

North Dike	(12 m thickness; 100 m minimum strike length)
Central Dike	(39 m thickness; 350 m minimum strike length)
South Dike	(10 m thickness; 250 m minimum strike length)

The Central Dike progressively widens from 10 to 39 m in a west to east direction and thus remains open to the east beyond the limits of visible outcrop. The main exposure, within the eastern part of the dike (UTM co-ordinates: 578287E, 5431689N; Zone 17), reveals a subtly zoned pegmatite that consists of the following units:

- sodic aplite border zone, 5 to 20 cm thick
- spodumene-rich pegmatite (muscovite-potassium feldspar-quartz-green spodumene-albite)
- central quartz-rich core zone
- lime green muscovite-rich patches
- late dikes of spodumene pegmatite

The sodic aplite border zone occurs along both the north and south contacts as a sugar texture, fine-grained white to light pink friable rock. Minor phases include red garnet and sparse black specks of possible tantalum-niobium oxide minerals. Toward the centre of the dike, a spodumene-rich pegmatite assumes dominance that subsequently grades into a 5 to 10 m by 90 m quartz-rich core zone. This zone consists of 70 to 80% massive white quartz and contains the coarsest blocky potassium feldspar (82 by 95 cm) and spodumene megacrysts (5 by 70 cm) in the entire pegmatite system. Small, blob-like masses, rich in lime green muscovite (80%) and augmented by orange garnet, albite and spodumene, occur sparsely in the core zone. These minerals range in size from 5 by 8 cm to 60 cm by 1.3 m. Rust-stained cavities characterize spodumene megacrysts within and proximal to these muscovite-rich domains. The cavities are due to inclusions of weathered sphalerite. Late dikes of spodumene pegmatite transect the aplite border zone and progress into the granodiorite host rocks, thus indicating a relatively early crystallization for the aplite that could have resulted in a rapid, pressure quench crystallization (Jahns 1982).

The west parts of the Central Dike, however, reveal a striking contrast in the greater abundance of sodic aplite layered with coarse-grained spodumene granite, quartz-ballpeen-texture dark mica-albite rock and muscovite albitite units. There are also only small patches of quartz-rich core zone material, which have entirely disappeared at the west exposure of the Central Dike.

RARE-ELEMENT MINERALIZATION

Black oxide minerals that likely contain tantalum and niobium were identified in a variety of settings within the Case pegmatite system, composed of the following phases:

1. aplite border zone
2. muscovite-potassium feldspar-quartz-green spodumene-albite pegmatite
3. spodumene granite near western end of the Central Dike
4. muscovite albitite layer (western limit of exposure)
5. spodumene-albite-quartz pegmatite patches in quartz-ballpeen texture dark mica-albite rock (west limit of exposure)

Electron microprobe analysis to date has only analyzed oxide phases from the spodumene-rich pegmatite unit from the main exposure. These data reveal a iron-suite trend (*see* Figure 39.14) with compositions mostly in the manganocolumbite field (average = 32.83% Ta_2O_5; range = 22.65 to 49.91%). The Ta/(Ta+Nb) ratios, however, reveal a significant range that almost enters into the manganotantalite field (*see* Figure 39.14). Beryl is subtly present as white to faint blue crystals up to 5 cm diameter and mostly occur within the spodumene-rich pegmatite.

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40. Project Unit 99-316. Operation Treasure Hunt Bedrock Geology Map Compilation

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INTRODUCTION

As a part of the Operation Treasure Hunt (OTH) project, initiated in April 1999, a bedrock geology map compilation project was undertaken for a portion of northwestern and northeastern Ontario. The objective of the project is to assemble the most recent geoscience information to encourage the generation of new exploration targets. The 1:250 000 scale map sheets to be completed are shown on Figure 40.1. The project continues until March 2002, during which publication of individual map sheets will be intermittent before the final deadline.

The new maps integrate the existing 1:1 000 000 scale compilation (Ontario Geological Survey, 1991) with recent bedrock geology mapping, new tectonic interpretations, and recent airborne geophysical surveys, as well as incorporating the Ontario Mineral Deposit Inventory database.

Project development was initiated by F. Santaguida who reported on the methodology developed to produce the maps (Santaguida 2000). A preliminary version of one of the compilation map sheets (Thunder Bay) was made available for comment and review prior to submission for publication. The sample map was on display in all the offices of the OGS Resident Geologist Program for 2 weeks in June 2000. A questionnaire accompanying the map was devised to prompt specific responses to individual map components such as the legend structure, the mineral deposit classification system, and the overall map design. The questionnaire was also aimed at identifying the particular map components geologists and prospectors look for and whether these components were present on the sample map. The map was also sent to the regional prospector's associations for overall comment and review. From the comments and suggestions received, several improvements to the map content and design have been made.

Working draft copies of the maps are sent to the local office(s) of the OGS Resident Geologist Program, for review and comment. Geoscientists of the Precambrian Geoscience Section, Ontario Geological Survey, with knowledge of the geology of the map area, were also asked for comment. Additions and corrections to the Ontario Mineral Deposit Inventory database and the geology are then incorporated into the draft map.

PROGRESS TO DATE

Three maps have been completed and released in 2001 (*see* Figure 40.1): Quetico Map 2663, Thunder Bay Map 2664 and Schreiber Map 2665. The White River Map 2666, and the Michipicoten Map 2669 are in press and will be released shortly. The Long Lac (42E) and Hornepayne (42F) map sheets are currently being compiled and will be completed by March 2002.

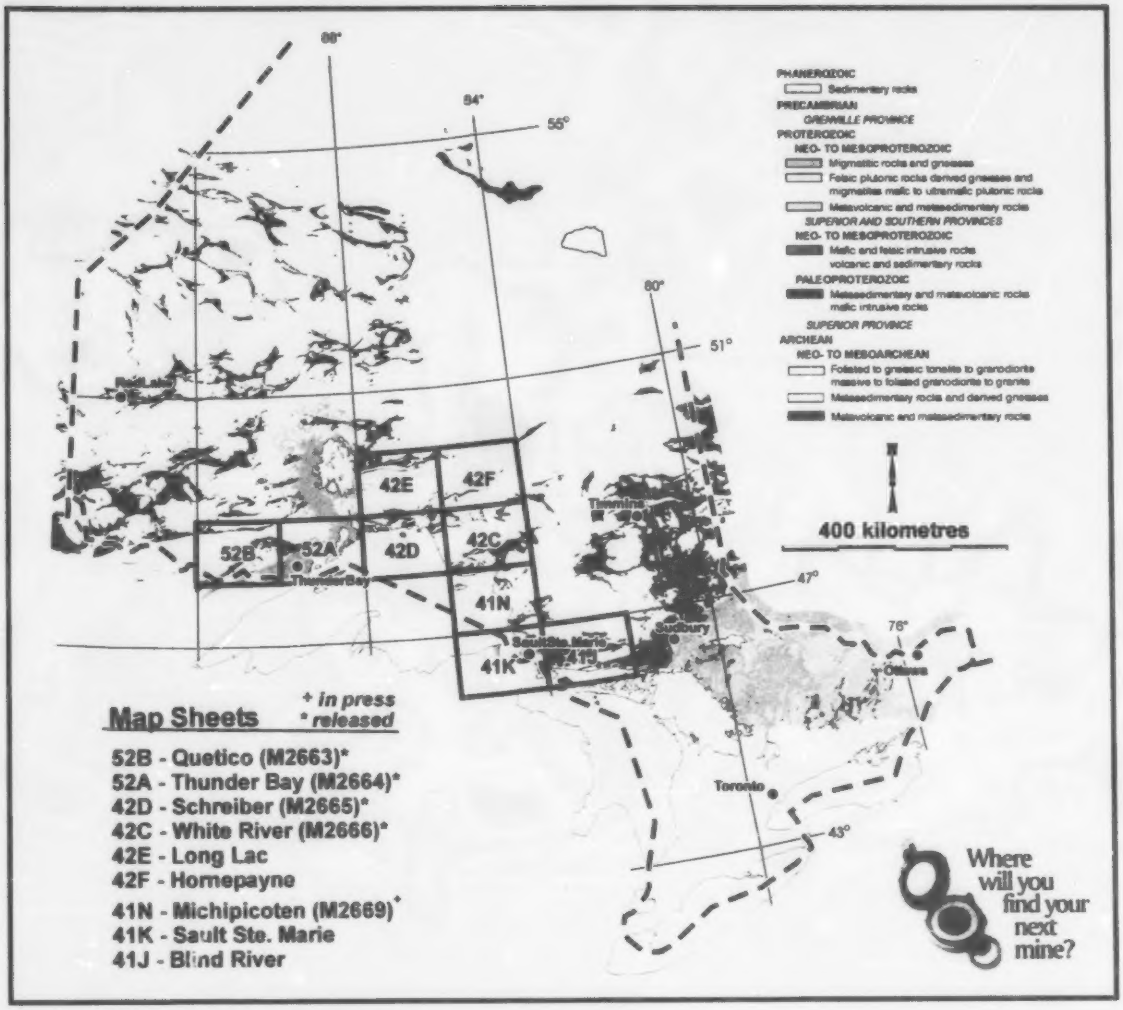
88°
84°
55°
80°
51°
47°
76°
43°
Red Lake
Thunder Bay
Timmins
Sault Ste. Marie
Sudbury
Ottawa
Toronto
52B
52A
42D
42E
42F
42C
41N
41K
41J
PHANEROZOIC
Sedimentary rocks
PRECAMBRIAN
GRENVILLE PROVINCE
PROTEROZOIC
NEO- TO MESOPROTEROZOIC
Migmatitic rocks and gneisses
Felsic plutonic rocks derived gneisses and migmatites mafic to ultramafic plutonic rocks
Metavolcanic and metasedimentary rocks
SUPERIOR AND SOUTHERN PROVINCES
NEO- TO MESOPROTEROZOIC
Mafic and felsic intrusive rocks volcanic and sedimentary rocks
PALEOPROTEROZOIC
Metasedimentary and metavolcanic rocks mafic intrusive rocks
SUPERIOR PROVINCE
ARCHEAN
NEO- TO MESOARCHEAN
Foliated to gneissic tonalite to granodiorite massive to foliated granodiorite to granite
Metasedimentary rocks and derived gneisses
Metavolcanic and metasedimentary rocks
N
400 kilometres
Map Sheets
+ in press
* released
52B - Quetico (M2663)*
52A - Thunder Bay (M2664)*
42D - Schreiber (M2665)*
42C - White River (M2666)*
42E - Long Lac
42F - Hornepayne
41N - Michipicoten (M2669)+
41K - Sault Ste. Marie
41J - Blind River
Where will you find your next mine?

Figure 40.1. Bedrock geology map showing 1:250 000 bedrock compilation areas (Operation Treasure Hunt project) and products released to date.

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41. Project Unit 00-303. Physical Rock Properties Study in the Matheson and Kirkland Lake Areas

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INTRODUCTION

While geophysical data provide knowledge of regional patterns of physical property variations, interpretation of these data sets in terms of lithological variations is difficult unless one has some prior knowledge of the actual physical properties of rocks. The recognition of the value of a physical properties database in the interpretation and modelling of geophysical data is steadily increasing as a result of improved techniques and procedures used in the search for mineralized deposits.

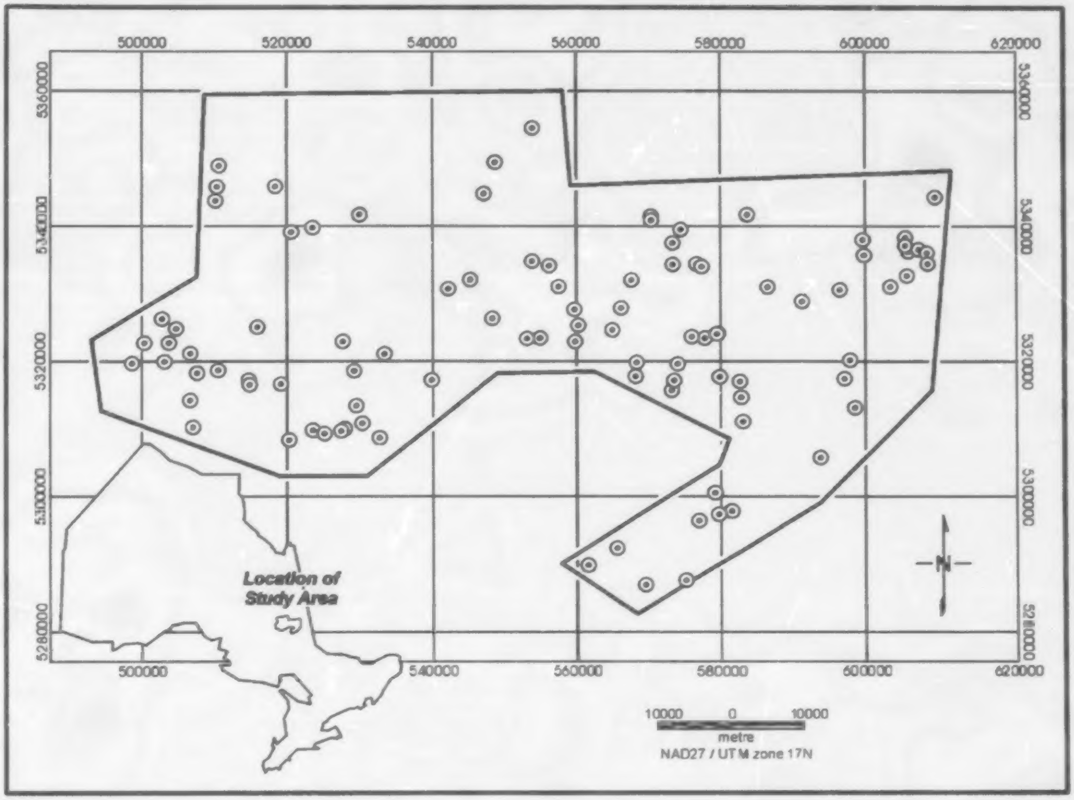
This project is being carried out through an Ontario Geological Survey–McMaster University Collaborative Project Agreement, under the Operation Treasure Hunt (OTH) initiative. The goals of the project are to characterize the petrophysical properties of rocks from 2 areas of the Abitibi greenstone belt and to determine if certain lithologies or mineralization types can be discriminated on the basis of those properties. The physical properties that are measured in this study are magnetic susceptibility and remanence, density, porosity, electrical conductivity, seismic properties and radioelement concentration. By examining the petrophysical signature in areas of existing mineralization, the aim is to increase the accuracy of geophysical interpretations toward the identification of ore deposits.

CURRENT PROGRESS

This project began with sample collection during the summer field season of 2000. During the following year, the first 100 samples were analyzed as part of an BSc (Hons) thesis project (Deschamps 2001). This report presents the results of physical rock property measurements conducted from this subset of 100 rocks from the Kirkland Lake block. The summer of 2001 was used to prepare the remaining 374 samples and begin the physical rock property measurements. These determinations will continue into the fall of 2001 and the final results and report can be expected by December 2001.

LOCATION, SAMPLE COLLECTION AND PROCEDURES

The project area was chosen to coincide with the Matheson and Kirkland Lake airborne geophysical surveys flown as part of the Operation Treasure Hunt initiative in 1999 to 2000 (Figure 41.1). The Matheson survey area covers a large section of the Porcupine–Destor deformation zone, while the Kirkland Lake block includes the Larder–Cadillac deformation zone. Samples were collected from major representative lithological units within the survey blocks and, where possible, from areas of known mineralization. Some physical property measurements are vector quantities; therefore, it was necessary to obtain fully oriented samples. Each sample was marked in the field with the known orientation so that it could be reoriented in the lab to its original position. At each location, the UTM coordinates and a lithological description were noted. In the laboratory, 3 cylindrical cores (specimens) were drilled from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Location of Study Area
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metre
NAD27 / UTM zone 17N

Figure 41.1. Location map of study area and sample sites.

each sample and marked with the orientation for that sample. The cores were sliced to produce 1-inch long, 1-inch diameter specimens. For some samples, it was not possible to obtain 3 cores because of either the size or the friability of the sample. Of the 474 oriented samples collected, a subset of 100 samples was initially measured for density, magnetic susceptibility and magnetic remanence. The locations of these 100 samples are shown in Figure 41.1.

MEASUREMENT METHODOLOGY

Instrument Specifications

Property	Instrument	Instrument			Measurement	
		Accuracy	Sensitivity	Range	Accuracy	Sensitivity
Specific Gravity	Analytical Balance	0.0005 g	0.0001 g	0 – 30 g	0.01 g/cm^3	0.01 g/cm^3
Magnetic Susceptibility	Bartington MS-2	1 × 10^{-6} cgs	1 × 10^{-5} cgs	10^{-6} – 10 cgs	1 × 10^{-6} cgs	1 × 10^{-6} cgs
Magnetic Remanence	Schonstedt SSM-1a	5 × 10^{-6} emu/cm^3	5 × 10^{-6} emu/cm^3	1 – 10^{-6} emu/cm^3	1 × 10^{-5} emu/cm^3	1 × 10^{-5} emu/cm^3

Specific Gravity

The specimens were cleaned and left to dry for a minimum of 7 days to ensure moisture elimination. The dry specimens were weighed in air then submerged in water and weighed again. Using Archimedes' principle, the specific gravity was determined using the equation

$$\rho = W_d / (W_d - W_w)$$

where ρ is the specific gravity and W_d and W_w are the dry and submerged weights, respectively. The volume of the specimen can then be determined from the specific gravity and dry weight. This volume information is used in the determination of other physical property measurements, such as magnetic susceptibility where volume correction is required.

Magnetic Susceptibility

Magnetic susceptibility (MS) measurements were made using the low frequency (0.1 cgs) setting. The MS-2 sensor is configured for standard paleomagnetic specimens. The susceptibilities are measured at a standard volume of 10 cm^3, so each of the measurements needs to be volume corrected. This is calculated using

$$\text{Volume-corrected MS} = (\text{observed MS} \times 10) / \text{volume}$$

Calibration of the instrument was achieved through reference to two points; the susceptibility of air which by definition is equal to zero, and a reference sample with known susceptibility. The manufacturer claims the instrument is linear over the full measurement range. Repeat calibration of the instrument was carried out after every 10 measurements.

Magnetic Remanence

Magnetic remanence (MR) was measured using the standard six-orientation convention giving 4 measurements for each direction of x, y and z. The intensity is simply the length of the vector. The orientation of the magnetic vector relative to the specimen is calculated from the 3 orthogonal magnetic components. Rotation back to current horizontal reference frame is achieved by correction for the known specimen orientation. The accuracy of the orientation of the vector is ±5%.

RESULTS

Analytical methods were modelled after Henkel (1991, 1994) and Airo (1999), both of whom used single-property (univariate) and multi-parameter (bivariate) graphs to depict the physical rock property data.

Univariate Analysis

The distribution of density values ranges from 2.5 to 4.0 g/cm^3 (Figure 41.2a). Common densities for crystalline rocks lie between 2.55 and 3.2 g/cm^3 (Henkel 1991). Values above these are indicative of massive sulphide deposits or iron ores, which have high pyrrhotite (density of 4.6 g/cm^3) or magnetite (density of 5.2 g/cm^3) contents. In Figure 41.2b, the MS measurements show the typical bimodal

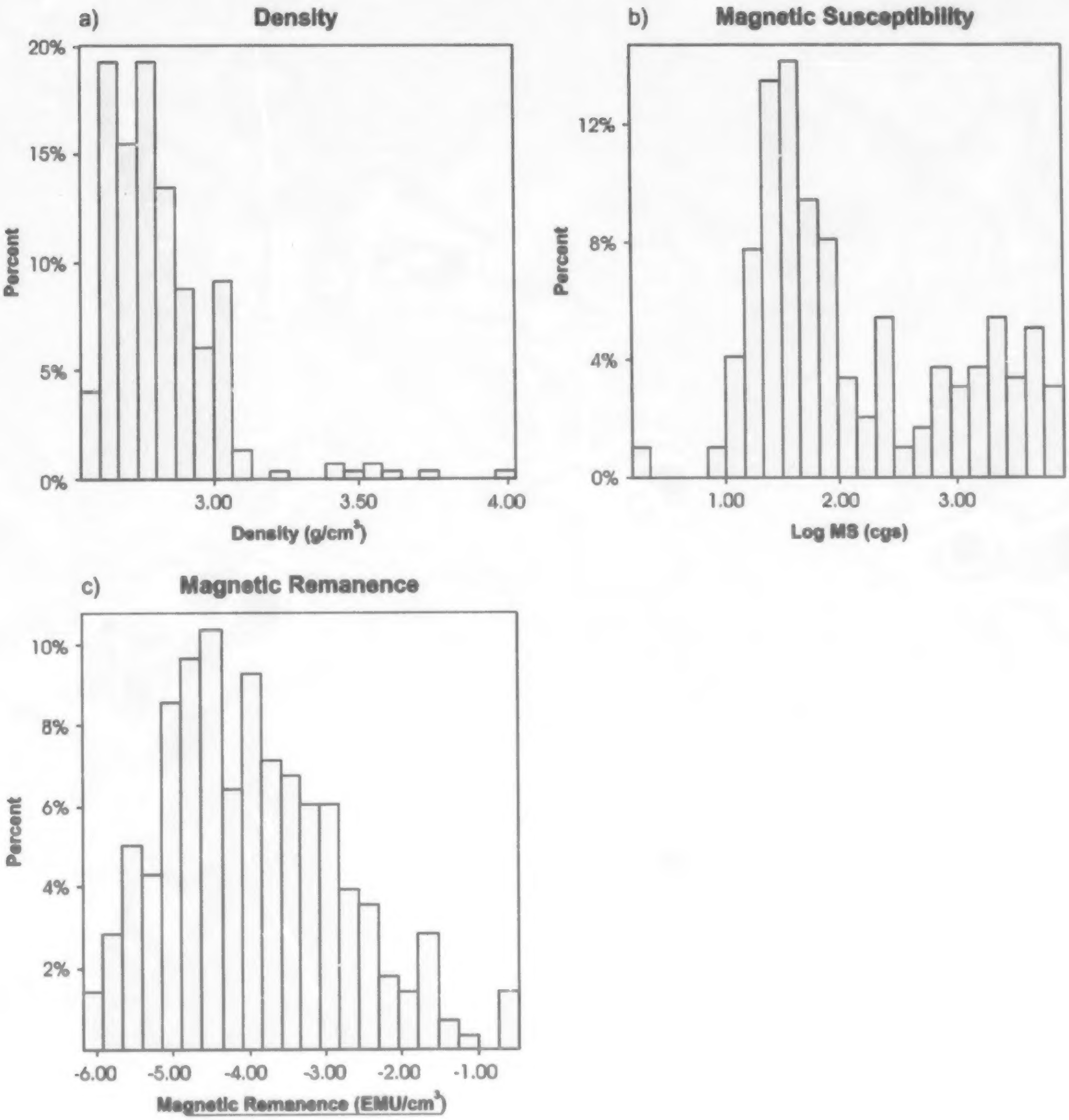

Figure 41.2. Frequency histograms for a) density, b) magnetic susceptibility, and c) magnetic remanence intensity.

distribution that is common for Archean rocks (Henkel 1991; Airo 1999). This is due to the presence of 2 groups of rocks that are dominated by different magnetic mineral types, paramagnetic (iron-magnesium silicates with lower susceptibilities) and ferrimagnetic minerals (magnetite and pyrrhotite with higher susceptibility). The paramagnetic susceptibilities range from 10 to 100 cgs and account for most of the rock types (the larger dominant peak), while the ferrimagnetic types range from 1000 to 10 000 cgs.

The distribution of intensity is not quite symmetrical (Figure 41.2c), being slightly skewed to the higher intensity values. Intensity is important because it can have a large effect on magnetic anomalies. High remanence values are often associated with banded iron formations and massive sulphide deposits.

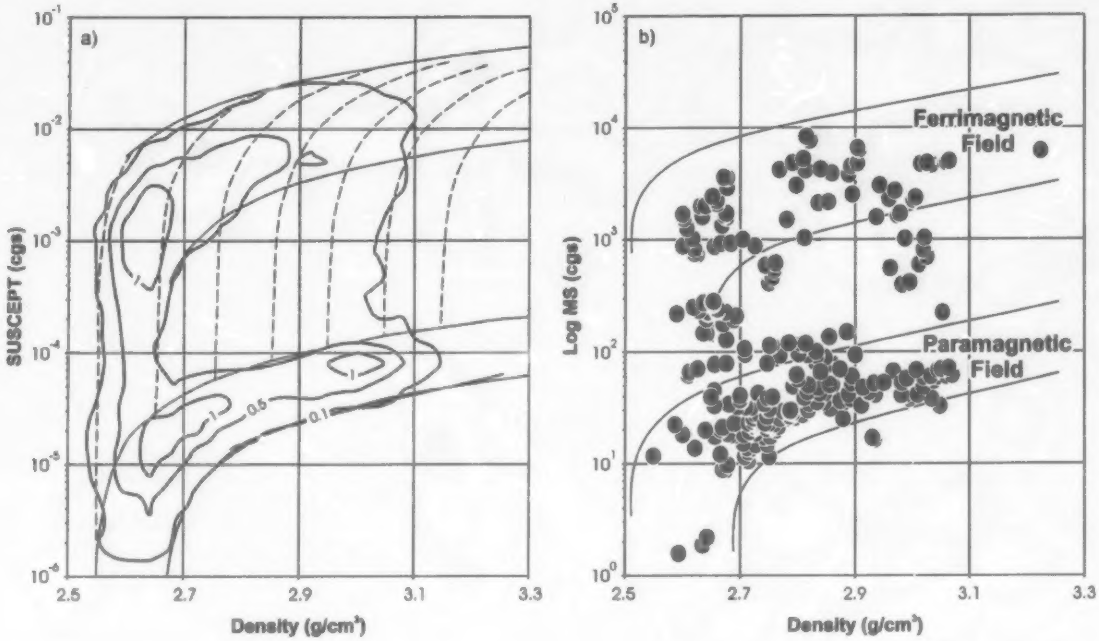

Figure 41.3. a) Susceptibility–density plot with paramagnetic and ferrimagnetic fields with mixing lines *after* Henkel (1991); b) susceptibility–density plot of first 100 samples with paramagnetic and ferrimagnetic field lines.

Bivariate Analysis

Henkel (1991) defines 2 distinct trend fields on a density–MS plot of nearly 30 000 Precambrian rock samples (Figure 41.3a). The 2 main fields near the top and the bottom are the paramagnetic and the ferrimagnetic trends. The mixing lines connect the 2 fields and represent rocks that contain both paramagnetic and ferrimagnetic minerals. The density–susceptibility plot (Figure 41.3b) shows the trends of the paramagnetic (iron-magnesium silicates) and ferrimagnetic minerals (magnetite and pyrrhotite), as well as the samples that fall into the mixing area.

The specimens from this project exhibit a high predominance of samples having paramagnetic signatures. This is to be expected since greenschist-facies metamorphism involves the systematic destruction of magnetite to be replaced by ferromagnesian silicates such as epidote and chlorite.

A density–susceptibility plot for volcanic rocks shows that volcanic rocks also plot within the 2 fields. Most of the volcanic rocks are paramagnetic, ranging from 20 to 100 cgs with densities from 2.6 to 3.1 g/cm^3. There is also a cluster within the ferrimagnetic trend field, which shows that, although the majority of the volcanic rocks contain primary magnetite, only a few have retained that magnetite through metamorphic episodes.

The distribution of granites shows 2 distinct types, those that are paramagnetic, and those that are ferrimagnetic. This could be due to a reaction that produces magnetite and potassium feldspar from biotite during the cooling of felsic plutons. Sedimentary rock types are mostly paramagnetic with only a few containing magnetite. This is expected since most sediment rarely contains magnetite.

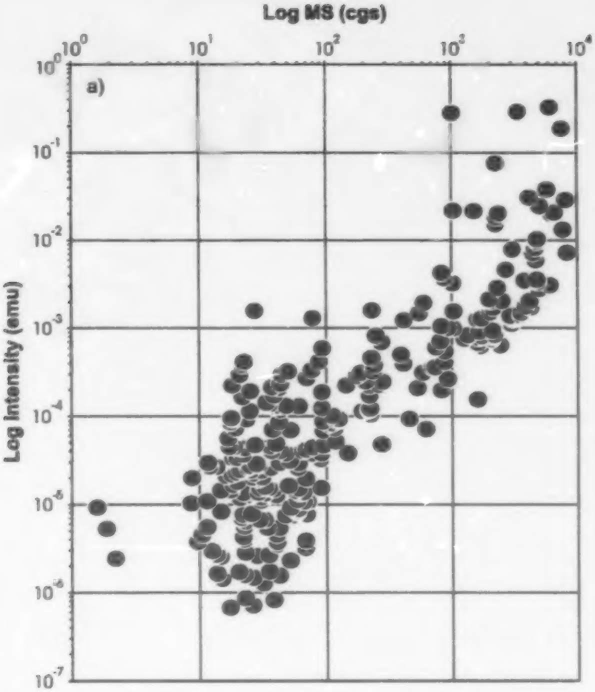

Figure 41.4. Intensity–susceptibility plot for 100 samples.

An MS–intensity scatter plot shows a distinct linear relationship between these 2 magnetic properties (Figure 41.4); remanence intensity increases linearly with increasing MS. Such a broad similarity in signal suggests that many of the samples have a common magnetic mineralogy. Again, considering the regional nature of the greenschist metamorphism, this is not surprising.

DISCUSSION

Implications for Lithological Separation

Magnetic properties can be used to distinguish magnetite-bearing rocks (ferrimagnetic) from nonmagnetite-bearing rocks (paramagnetic). The density–magnetic susceptibility (MS) plots show this distinction for both volcanic rocks and granitoid rocks; mafic volcanic rocks are mostly paramagnetic, while felsic granitic rocks can be both. The density–MS diagram is also useful for determining the amount of metamorphism in the area. Figure 41.3b shows that several samples lie within the mixing area between the 2 mineral fields. This is a result of the abundant greenschist-facies metamorphism. In this type of alteration, chlorite is produced in large amounts and magnetite is destroyed in the process. This causes the sample to move from the ferrimagnetic field to the paramagnetic field, resulting in a large number of samples at different stages of metamorphism, in the mixing field.

Granitic rocks have been divided into 2 types based on chemistry and inferred source rocks: I-type (igneous) and S-type (sedimentary) granites (Chappell and White 1974). Ishihara (1977) also classified granitic rocks into 2 types based on the opaque mineral content; ilmenite–S-type (less than 0.1% magnetite) and magnetite–I-type (greater than 0.1% magnetite) series. Since the different types of granitic rocks are associated with different mineralization styles, this method offers potential for discriminating deposits based on MS.

The MS–intensity plot (*see* Figure 41.4) shows that these 2 variables generally increase in an approximately linear manner. A small subset with low intensity and low susceptibility values corresponds to the paramagnetic dominated rocks, mostly volcanic rocks and sedimentary rocks. The linear portion of the trend represents increasing magnetite content, some of which might be associated with the metamorphic destruction of magnetite. The highest values are those belonging to banded iron formations and massive sulphides, with larger remanence components than susceptibility. In this case, the remanence direction becomes much more important since it accounts for a large portion of the anomaly associated with the source mineralization.

CONCLUSIONS

The purpose of this study was to characterize the petrophysical properties of rocks from a region of the Abitibi greenstone belt and to determine if certain lithologies can be discriminated on the basis of those properties. Based on the analysis of physical property measurements, separately, comparatively and spatially, the following conclusions can be made. Magnetic mineralogy can be determined from susceptibility–density plots and the degree of metamorphism in the area can be estimated. It is also possible to distinguish between different granitic rocks and use this distinction as a proxy to search for associated mineralization. Extremely magnetic lithologies can be separated, and the remanence direction taken into account when using magnetic anomalies to predict the orebody size or location. The integration of all of these techniques into one approach allows for the separation of several different key lithologies and mineralization types.

The next immediate goals are to continue the analyses on the remaining samples in the collection to increase the density of measured values and also to complete the analysis of variation between lithologies to verify that certain rocks have statistically different responses. Further goals should include a comparison of the spatial variations in magnetic susceptibility and intensity with aeromagnetic maps. An analysis of variation in remanence direction should be conducted to determine the effect on anomaly strength.

ACKNOWLEDGMENTS

Field and laboratory work were supported through an Ontario Geological Survey–McMaster University Collaborative Project Agreement, under the Operation Treasure Hunt initiative, Ontario Ministry of Northern Development and Mines. Without the extensive knowledge and experience of B. Polk and D. Robertson, the field work for this project would not have been possible. Thanks to B. Berger and T. Livingstone of the Ontario Geological Survey for every kind of help imaginable. Grateful thanks to R. Singh, A. Duskocy and D. Moore for their invaluable help with the lab work, sample preparation and measurements.

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42. Project Unit 99-318. Thick Overburden Geochemistry Methods

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INTRODUCTION

This paper describes the fieldwork carried out as part of the third and final field season of the "Deep Penetrating Geochemistry" (DPG) project. DPG is a joint project between the Ontario Geological Survey (OGS), the Geological Survey of Canada (GSC) and the Canadian Association of Mining Industry Research Organisations (CAMIRO) that is investigating geochemical techniques capable of detecting mineralization through the thick overburden of the Abitibi clay belt at 3 known mineral occurrences. Sedimentary Geoscience Section staff's involvement in DPG is part of a longer-term project by the OGS, with the same objectives, that has been referred to as the Thick Overburden Geochemistry initiative (TOG). The objectives of the 2 projects are similar and therefore the results will be combined and released together.

Another aspect of the TOG initiative is the investigation into "Forest Rings", which are large, circular features visible from the air. A report on the work carried out over the last 2½ years on this part of the TOG work will also be released in 2002.

Results from the first 2 years of work have been released in several publications (Hamilton et al. 2001; Hamilton and Cranston 2000; Hamilton 2000a, 2000b). The final reporting date was rescheduled from spring 2001 to early 2002 because the project was extended by a year and the 2001 work was a direct extension of the earlier work. Parts of the TOG initiative are ongoing and limited fieldwork on the next phase was carried out this field season, the activities of which are reported here.

OBJECTIVES

The objectives of both the OGS-CAMIRO studies and those carried out by the OGS alone are similar:

1. To investigate geochemical techniques that are capable of detecting mineralization through thick, young exotic overburden.
    - The overburden in the Abitibi is only 8 to 12 Ka in age and is predominantly glaciolacustrine clay. The chemical composition of the mineral matrix of such materials usually bears no relation to the underlying chemistry of bedrock and therefore the work has focused on using partial extractions, which are designed to remove the weakly bound, transported metals from the surface of mineral grains, oxides and/or organic material.
2. To compare partial extraction techniques against each other.
    - Numerous techniques are commercially available but various workers have reported mixed results when using them. In addition to determining if they are capable of detecting a signal from mineralization, it is also important to compare the performance between methods.

3. To determine the geochemical mechanisms that are responsible for the transport of metals to surface in thick overburden environments.
    - Until recently, it was not widely believed that metals could be transported through as much as 30 m of fine-grained glacial materials in 8 to 10 Ka. To understand the significance of any geochemical signals found over mineralization, one must understand the processes that have caused them.

BACKGROUND

The DPG project focused on 3 mineral deposit sites that were selected from a possible list of over 80 and a shortlist of about 15. The sites are: the Marsh Zone, owned by St. Andrew Goldfields Limited; Cross Lake Mineral's Sheraton Township property; and the Half Moon Lake property, held by Prospector's Alliance Limited (PAL). The Marsh Zone is a syenite-hosted gold deposit overlain by clay and peat and the other 2 sites are base metal properties overlain by sand/clay and clay respectively. The overburden thicknesses vary from 20 to over 50 m. The Marsh Zone and Cross Lake were selected for detailed subsurface investigations that included drilling programs.

The work on the 3 sites included surface SP surveys, determination of pH in soils and geochemical sampling for analysis by a variety of techniques. More specifically, a number of commercially available and several experimental partial-digestions were applied to the samples including Enzyme Leach, Mobile Metal Ion (MMI), sodium-pyrophosphate, hydroxylamine-HCl (several variants), water-soluble extraction and an acetate leach. Aqua Regia, a strong acid digestion, was also applied to both the humus and B-horizon samples to provide an indication of the "total" metal concentration.

Some of these digestions can also be referred to as "selective" digestions because they are purported to selectively digest a particular component of the metals within the sample, such as Mn oxides in the case of Enzyme Leach or organic material in the case of sodium pyrophosphate. As mentioned, they are all intended to extract the weakly-bound and possibly transported component of metals that adhere to the mineral grains, oxides or organic material and leave undigested the mineral matrix of the soil. This is important in areas such as the Abitibi clay belt where most of the parent materials of the mineral soil are exotic and have been transported over long distances. Therefore, the metal content of such material would have no bearing on the underlying bedrock.

At Cross Lake and the Marsh Zone, a drilling and monitoring-well installation program was carried out. A total of 15 shallow wells to 9 m, and 3 deep wells to bedrock were drilled at the Marsh Zone. A total of 37 shallow wells and 3 deep wells to bedrock were drilled at Cross Lake. During drilling, samples from 3 levels at the Marsh Zone and 4 levels at Cross Lake were tested for pH and redox. Monitoring wells were installed in all boreholes and groundwater was later sampled and tested for metals, major cations and anions, pH, oxidation-reduction potential (ORP), dissolved CO_2 and H_2S. Down-hole spontaneous potential (SP) was also carried out. Water levels and hydraulic conductivities were determined to allow groundwater flow-directions and velocities to be calculated.

There are 3 forest-ring sites being investigated in detail; one north of Hearst, which is referred-to as "Bean" and the other 2 north of Timmins, referred-to as Thorn-North and Thorn-South. They were selected for their accessibility by road. At the time the investigation was initiated, the causes and processes that formed the rings were unknown. However, an initial orientation survey in the fall of 1998 provided sufficient data to support our hypothesis that the rings were centred on geological sources of negative charge. All 3 of the sites have since been drilled, mostly with shallow auger holes, but at least one hole was drilled to rock on each site. Monitoring wells were installed in all holes and tests similar to those used at the mineral deposit sites were carried out.

2001 FIELD SEASON

The work described above was carried out mostly in 1999 and 2000 and this summer's field work involved "mop-up" of aspects of the earlier work that had not been fully completed or which required follow-up work. The data collected were necessary to complete datasets for each of the sites, which will be needed to complete the final report. Additional fieldwork was initiated that included a new study at Cross Lake and the Marsh Zone.

The mop-up work at the ring sites included:
- repair of wells that degraded over the winter
- water levels and surveying
- down-hole SP
- down-hole temperature surveys

The mop-up work at Cross Lake and Marsh Zone included some or all of:
- water levels and surveying
- down-hole SP
- down-hole temperature surveys

A new initiative begun in 2001 focused on the possibility of using platinum-based probes to determine the true redox properties of soils and, in particular, the redox response over mineralization relative to adjacent areas. Currently, there are no ideal ways of determining the oxidation-reduction potential of soils. Solution-based electrodes, such as the standard Cu-$CuSO_4$ pot used in SP surveys, require very consistent moisture conditions along the line or they produce moisture or ionic-strength related anomalies. Platinum probes polarise in air or in air-saturated solutions and require very long amounts of time to depolarise. The work this summer involved inserting dozens of platinum electrodes into saturated and unsaturated soil along lines that transect mineralization at Cross Lake and the Marsh Zone. They were left for a number of weeks to equilibrate and depolarise. Every week or so, readings were taken at every probe along the line against a stationary electrode. Probes were inserted at 2 depths along each line and 2 lines were tested on each site.

This was "orientation" fieldwork designed to determine if larger investigations were warranted. Initial results show that all the probes along the line depolarise in a particular direction and take about 6 weeks for the readings to equilibrate. This information will allow a larger-scale survey to be designed next year if time and resources permit.

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43. Project Unit 99-315. OTH Lake Sediment Geochemistry

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INTRODUCTION

The Operation Treasure Hunt (OTH) high-density lake sediment geochemistry program consists of lake sediment sampling and water limnological testing. During the 2001 field season, 3 project areas were completed (Figure 43-1). The Lac des Iles project area in northwestern Ontario is located approximately 50 km north of Thunder Bay. The Sudbury-River Valley project area covers the City of Greater Sudbury and extends eastward to the River Valley area. Contiguous to the east of the River Valley area is the Temagami survey area which extends almost to the Quebec-Ontario border. Large parts of the surveyed areas are considered to have relatively high mineral potential, for example, the Sudbury Basin and the Temagami greenstone belt.

High density (~1 sample per 2.5 km^2) lake sediment sampling has not previously been completed over the 3 study areas. Low density lake sediment sampling (~1 sample per 12 km^2), however, was undertaken throughout these areas under the National Geochemical Reconnaissance (NGR) lake sediment program. The NGR program was carried out jointly by the Geological Survey of Canada (GSC) and the Ontario Geological Survey (OGS) during the late 1970s and early 1980s.

FIELDWORK

The fieldwork for these lake sediment surveys was carried out by a private vendor under contract to the Ontario Geological Survey (OGS). Standard OGS sampling methodologies were utilized and adherence to these protocols was monitored by OGS staff as detailed in the quality control section below. The fieldwork in the Lac des Iles project area was completed during June-July, 2001 with a total of 2237 samples collected. The Sudbury-River Valley-Temagami project areas were completed during the period June-August 2001 with a combined total of 3828 samples collected. All the sediment samples were submitted to the Geoscience Laboratory in Sudbury for preparation and analysis, of which the latter is still ongoing. Private contract laboratories will be utilized for some of the analysis, including that for platinum group elements.

Within the Sudbury-River Valley and Temagami areas, water samples were also collected and provided to Laurentian University. These samples will be analyzed for a variety of parameters, including trace metals, and the analytical data will form an important baseline dataset to assist in the evaluation of lake water quality throughout the region.

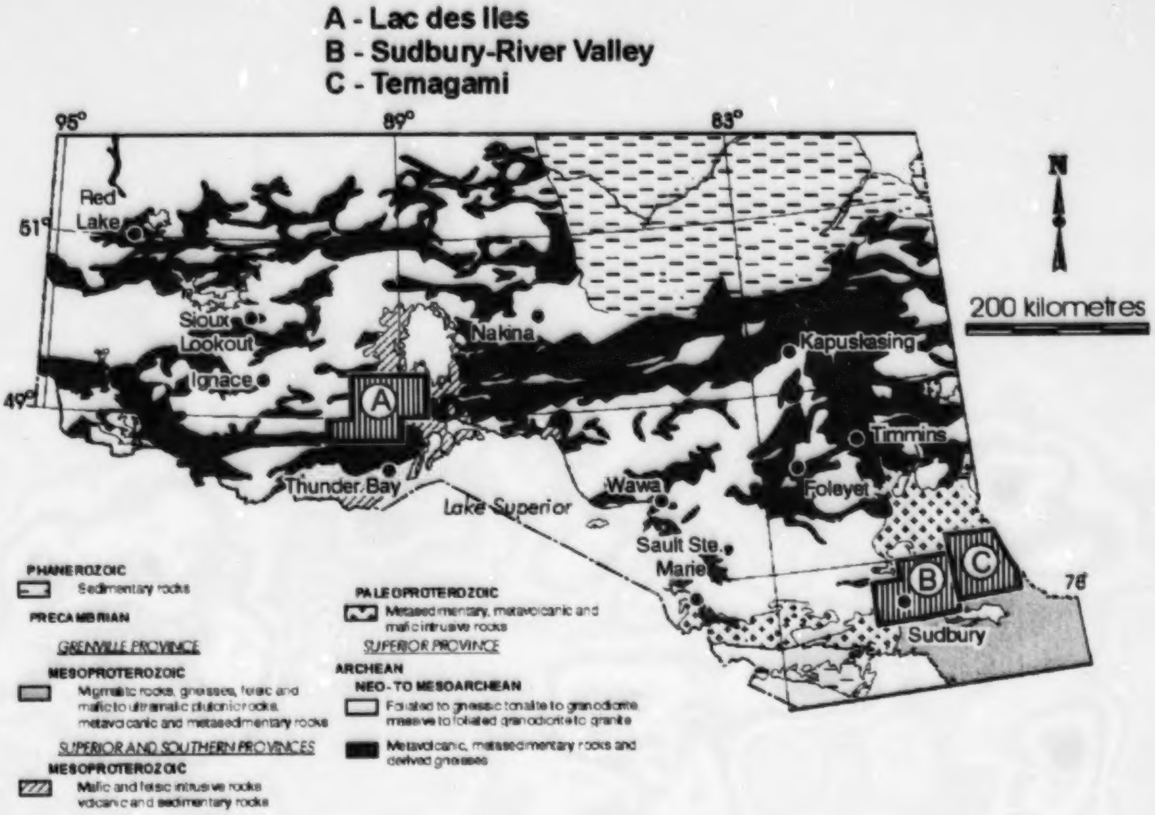
A - Lac des Iles
B - Sudbury-River Valley
C - Temagami
95°
89°
83°
51°
49°
76°
N
200 kilometres
Red Lake
Sioux Lookout
Ignace
Nakina
Kapuskasing
Timmins
Foleyet
Thunder Bay
Lake Superior
Wawa
Sault Ste. Marie
Sudbury
A
B
C
PHANEROZOIC
Sedimentary rocks
PRECAMBRIAN
GRENVILLE PROVINCE
MESOPROTEROZOIC
Migmatitic rocks, gneisses, felsic and mafic to ultramafic plutonic rocks, metavolcanic and metasedimentary rocks
SUPERIOR AND SOUTHERN PROVINCES
MESOPROTEROZOIC
Mafic and felsic intrusive rocks volcanic and sedimentary rocks
PALEOPROTEROZOIC
Metasedimentary, metavolcanic and mafic intrusive rocks
SUPERIOR PROVINCE
ARCHEAN
NEO- TO MESOARCHEAN
Foliated to gneissic tonalite to granodiorite massive to foliated granodioritetic granite
Metavolcanic, metasedimentary rocks and derived gneisses

Figure 43-1. Location of Operation Treasure Hunt Lake Sediment Surveys, 2001

ANALYTICAL METHODS

Laboratory analysis consists of nitric-aqua regia digestion of 0.5 gm of sample pulp followed by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma-optical emission spectroscopy (ICP-OES) to determine approximately 50 major, minor and trace elements. Nitric acid-aqua regia digestion attacks all sample matrix constituents, except for silicate minerals, and therefore is considered to be a nonselective, relatively strong partial extractant. Approximately 10 gm of sample pulp is pressed into briquettes prior to analysis by instrumental neutron activation analysis (INAA) for Au, As and a suite of 25 other elements. If sufficient sample puip is available, 10 grams of material will be analyzed by fire assay with ICP-MS finish to determine Au, Pt and Pd. Loss-on-ignition (LOI) is determined at 500°C, using a semi-automated furnace-gravimetric technique.

QUALITY CONTROL/QUALITY ASSURANCE PROCEDURES

Quality control/quality assurance (QC/QA) in the field is crucial to a successful geochemical sampling program. Quality control involves: 1) proactive measures at the time of sample collection; and 2) quality assurance procedures at all stages of the sample collection/handling/analysis process. To ensure that OGS protocols were adhered to, a rigid quality assurance program was instituted to ensure the integrity of samples collected and data acquired. The program involves 4 components:

1. A mandatory information and training session for the contractor prior to the commencement of field work. Follow-up information sessions and/or field visits by the OGS staff were done to ensure all aspects of sample protocols and requirements were understood and were implemented by the contractor.
2. The collection of method (field) duplicates by OGS staff at approximately 2% of lakes sampled. This procedure is intended to provide a fair determination of the contractor's performance with respect to sample collection and handling techniques, maintenance of water quality measuring equipment and recording of sample site locations. Field duplicates were sequenced-in with the Quality Control samples following fieldwork. After accounting for losses in precision due to analytical limitations, a level of precision of the field duplicate pairs is required to meet specifications outlined by the OGS. The analytical precision is determined from Thompson-Howarth plots (Thompson and Howarth 1978) using analytical data from sample pulp duplicates inserted into the sample batch(s) by the OGS. The field duplicate precision (also using Thompson-Howarth plots) is determined for all elements but a group of 5 indicator elements and LOI are used to rank the reproducibility of duplicates. Failure to meet the specifications outlined by the OGS resulted in monetary penalties to the contractor.
3. The insertion of Quality Control samples by the OGS, including method (field) duplicates, homogenized sample duplicates and certified reference standards (to determine laboratory accuracy) into the sample sequence between sample preparation and laboratory analysis. Sample numbers were altered to prevent detection of quality control samples by the laboratory. On average, every 10th sediment sample submitted was a quality control (QC) sample. The QC sediment samples consisted of field duplicates, analytical (pulp) duplicates, certified reference standards (CRS) and an internal (OGS collected) bulk standard. Field (method) duplicates were inserted with a frequency of 1 in 40. Analytical pulp duplicates were prepared by halving 1 in 40 of the dried sample pulps and inserting them into the sample sequence. CANMET certified reference standards (LKSD 1 to 4, Lynch 1990) and an OGS internal standard were also inserted as dried pulps between the sample preparation and analysis stages. On average, every 20th sample was either a CRS or an OGS internal standard. These 3 standards were inserted alternately so that each was repeated every 60th sample;
4. Monetary penalties for the collection/submission of inorganic samples and inadequate sample size.

RESULTS AND SUCCESS TRACKING

To date, over 320 significant discrete multi-site and/or multi-element anomalous areas have been delineated by the OTH lake sediment program and described in 8 Open File Reports. This includes: the Foleyet-Missinaibi area (Ontario Geological Survey 2000a) with more than 85 significant geochemical anomalies; the Armstrong-Lake Nipigon area (Ontario Geological Survey 2000b) with more than 70 significant geochemical anomalies and the Nakina-Longlac area (Ontario Geological Survey 2000c) with more than 75 significant geochemical anomalies. Data releases in 2001 containing OTH Pt, Pd and Au geochemical results include 3 reports which cover the Shining Tree to Matachewan area (Ontario

Geological Survey 2001a, 2001b, Russell and Hamilton 2001). These reports contain details of more than 45 significant geochemical anomalies.

In excess of 3000 claim units have been staked as a direct result of the published datasets. The OGS is also aware of several property transactions that have occurred as a direct result of these surveys and will continue to follow and track such success stories. The publication of the Fort Hope and Sioux-Lookout datasets over the course of the winter of 2001-2002 will certainly increase the number of significant anomalies and result in further exploration activity.

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44. Project Unit 01-305. OTH Sault Ste. Marie – Espanola Indicator Mineral Survey

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INTRODUCTION

Modern alluvium sampling for indicator minerals was carried out between Sault Ste. Marie and Espanola during the summer and early fall of 2001 (Figure 44-1). This project is one of 3 indicator mineral studies being completed under Operation Treasure Hunt (OTH). The other projects include the Kapuskasing Structural Zone (KAPZ) indicator mineral survey (Ontario Geological Survey 2001a, 2001b and 2001c) and a survey completed in 2001 over the James Bay Lowland. Traditionally, the modern alluvium sampling program of the Ontario Geological Survey has undertaken medium to high density sampling over structurally favourable shield terrain in Ontario in conjunction with Quaternary mapping. The Sault Ste. Marie – Espanola OTH program involved medium density (approximately 1 sample per 30 km^2) sampling over an area of approximately 21 000 km^2 that is host to 4 major river systems. These include: the Spanish; Aux Sables; Mississagi; and Garden rivers. Approximately 720 sites were identified for modern alluvium sampling. All samples will be processed to isolate kimberlite indicator minerals (KIMS), magmatic massive sulphide indicator minerals (MMSIMs®) and gold grains. It is expected that the maps, reports and databases generated by this survey will help to focus exploration efforts of prospectors and exploration companies.

The fieldwork for this survey was carried out by a private vendor under contract to the Ontario Geological Survey (OGS). Standard OGS sampling methodologies were followed (Morris and Kaszycki 1997, Morris et al. 1997, Stephenson et al. 1999) and adherence to these OGS protocols was monitored by OGS staff as detailed in the quality control section below. The samples are being processed by Overburden Drilling Management in Nepean Ontario and all microprobe work will be carried out at the Geoscience Laboratory in Sudbury.

SAMPLE PROCESSING

The sampling procedure requires that the contractors collect a minimum of 13 kg of modern alluvium. Upon receipt at the laboratory, the sample is disaggregated (if needed) and sieved to remove the +10 mesh (+2 mm) size fraction. The entire –10 mesh size fraction is then passed across a shaker table twice to produce a rough heavy mineral concentrate. Samples in which a pre-determined number of gold grains are seen during shaker table processing have the heavy mineral (table) concentrate refined by hand or mechanical panning to concentrate all contained gold grains and associated pathfinder minerals. Following the panning (if required), the tabled heavy mineral separates undergo a heavy liquid separation. The specific gravity of the heavy liquid used during this procedure is 3.2 g/cm^3. After heavy liquid separation the magnetic minerals are separated using an automagnet. The paramagnetic fractions (weakly, moderately and strongly paramagnetic) and non-paramagnetic fractions are isolated using appropriate

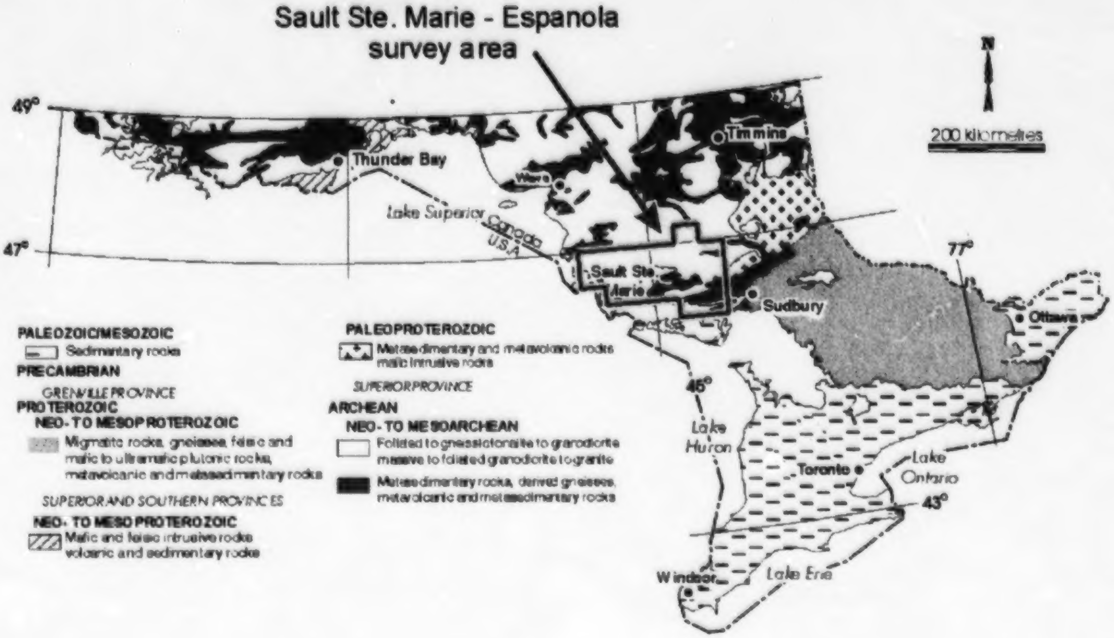
Sault Ste. Marie - Espanola survey area
N
200 kilometres
49°
47°
45°
43°
77°
Thunder Bay
Wawa
Timmins
Lake Superior
Canada
U.S.A.
Sault Ste. Marie
Sudbury
Ottawa
Lake Huron
Toronto
Lake Ontario
Windsor
Lake Erie
PALEOZOIC/MESOZOIC
Sedimentary rocks
PRECAMBRIAN
GRENVILLE PROVINCE
PROTEROZOIC
NEO- TO MESOPROTEROZOIC
Migmatitic rocks, gneisses, felsic and mafic to ultramafic plutonic rocks, metavolcanic and metasedimentary rocks
SUPERIOR AND SOUTHERN PROVINCES
NEO- TO MESOPROTEROZOIC
Mafic and felsic intrusive rocks volcanic and sedimentary rocks
PALEOPROTEROZOIC
Metasedimentary and metavolcanic rocks mafic intrusive rocks
SUPERIOR PROVINCE
ARCHEAN
NEO- TO MESOARCHEAN
Foliated to gneissic tonalite to granodiorite massive to foliated granodiorite to granite
Metasedimentary rocks, derived gneisses, metavolcanic and metasedimentary rocks

Figure 44-1. Location of Sault Ste. Marie – Espanola OTH indicator mineral survey.

methodology. The final heavy mineral concentrate (HMC) is sieved to obtain 4 size fractions (< 0.25, 0.25 to 0.5, 0.5 to 1.0 and 1.0 to 2.0 mm), each of which is weighed and placed in vials. Indicator mineral picking is then performed on the 0.25 to 0.5, 0.5 to 1.0 and 1.0 to 2.0 mm size fractions. A scanning electron microscope is used to confirm/check any questionable picked grains. The indicator minerals are then submitted to the Geoscience Laboratories for microprobe analysis.

QUALITY CONTROL/QUALITY ASSURANCE PROCEDURES

Quality control/quality assurance (QC/QA) in the field is crucial to a successful indicator mineral sampling program. Quality control involves: 1) proactive measures at the time of sample collection; and 2) quality assurance procedures at all stages of the sample collection/handling/analysis process. To ensure that OGS protocols were adhered to, a rigid quality assurance program was instituted to ensure the integrity of samples collected and data acquired. The program involves 5 components:

1. A mandatory information and training session for the contractor prior to the commencement of field work. Follow-up information sessions and/or field visits by OGS staff were done to ensure all aspects of sample protocols and requirements were understood;
2. The collection of method (field) duplicates by the OGS. This procedure is intended to provide a fair determination of the contractor's performance with respect to sample collection and handling techniques and recording of sample site locations.

3. Sieve tests to determine if submitted samples contain sufficient sand sized inorganic material as per OGS specifications;
4. The use of bulk sample weight and table feed weight criteria to ensure performance requirements have been met by the sample collection Contractor;
5. The application of penalties proportional to the degree of non-performance of OGS protocols and procedures.

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---------- 2001b. Results of modern alluvium sampling, Chapleau area, northeastern Ontario: Operation Treasure Hunt – Kapuskasing Structural Zone; Ontario Geological Survey, Open File Report 6063, 164p.

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Stephenson, D.M., Morris, T.F. and Crabtree, D.C. 1999. Kimberlite, base metal and gold exploration targets based upon heavy mineral data derived from surface materials, Opasatika Lake area, northeastern Ontario; Ontario Geological Survey, Open File Report 5982, 66p.

45. Project Unit 00-309. OTH James Bay Lowland Indicator Mineral Survey

R. Dyer[1] and D. Crabtree[1]

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INTRODUCTION

Modern alluvium sampling for indicator minerals was carried out over the James Bay Lowland during the summer and early fall of 2001 (Figure 45.1). This project is one of 3 indicator mineral studies being completed under Operation Treasure Hunt (OTH). The other projects include the Kapuskasing Structural Zone (KAPZ) indicator mineral survey (Ontario Geological Survey 2001a, 2001b and 2001c) and a survey completed in 2001 between Sault Ste. Marie and Espanola. The OTH program over the James Bay Lowland involved the collection of over 1000 samples covering an area of approximately 88 000 km^2. The survey covers a broad area of Paleozoic rocks, including the known clusters of kimberlite diatremes in the vicinity of the Attawapiskat River and Missisa Lake (Sage 2000). The samples are currently being processed to isolate kimberlite indicator minerals (KIMS), magmatic massive sulphide indicator minerals (MMSIMs®) and gold grains. It is expected that the maps, reports and databases generated by this survey will help focus exploration efforts throughout this region.

The fieldwork for this survey was carried out by the First Nations Communities of Attawapiskat, Kashechewan and Fort Albany under contract to the Ontario Ministry of Northern Development and Mines. The necessary training in OGS sampling protocols was provided by the Ministry. Standard OGS sampling methodologies were followed (Morris and Kaszycki 1997, Morris et al. 1997, Stephenson et al. 1999). The samples are being processed by Overburden Drilling Management in Nepean Ontario and microprobe work is currently ongoing at the Geoscience Laboratory in Sudbury.

PROJECT DESIGN CONSIDERATIONS

Sample sites were pre-selected using 1:50 000 scale topographic maps (mostly photomosaic maps) at an average spacing of 5 km along major rivers and tributaries from the Ekwan River in the north to the Albany River in the south. Significant input from the Attawapiskat, Kashechewan and Fort Albany First Nation communities was utilized to refine the sampling plan to those waterways which would most likely be navigable by freighter canoe. Because of their extensive knowledge of the river systems, contracting the field sampling to the First Nations communities was a logical step and provided an economic stimulus in numerous ways, not the least of which was opportunities for employment and training.

SAMPLE PROCESSING

The sampling procedure requires that the contractors collect a minimum of 13 kg of modern alluvium. Upon receipt at the laboratory, the sample is disaggregated (if needed) and sieved to remove

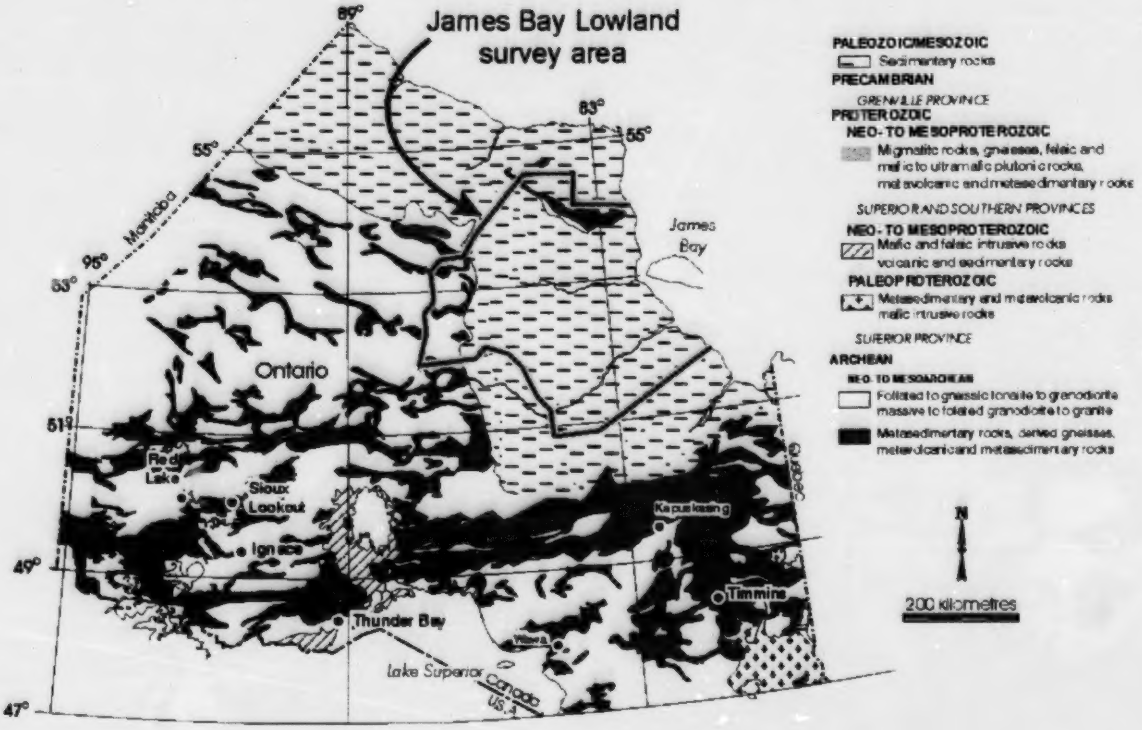
89°
James Bay Lowland survey area
83°
55°
55°
Manitoba
95°
53°
James Bay
Ontario
51°
Red Lake
Sioux Lookout
Ignace
Kapuskasing
Quebec
49°
Timmins
Thunder Bay
Wawa
Lake Superior
Canada
U.S.A.
47°
PALEOZOIC/MESOZOIC
Sedimentary rocks
PRECAMBRIAN
GRENVILLE PROVINCE
PROTEROZOIC
NEO- TO MESOPROTEROZOIC
Migmatitic rocks, gneisses, felsic and mafic to ultramafic plutonic rocks, metavolcanic and metasedimentary rocks
SUPERIOR AND SOUTHERN PROVINCES
NEO- TO MESOPROTEROZOIC
Mafic and felsic intrusive rocks volcanic and sedimentary rocks
PALEOPROTEROZOIC
Metasedimentary and metavolcanic rocks mafic intrusive rocks
SUPERIOR PROVINCE
ARCHEAN
NEO- TO MESOARCHEAN
Foliated to gneissic tonalite to granodiorite massive to foliated granodiorite to granite
Metasedimentary rocks, derived gneisses, metavolcanic and metasedimentary rocks
N
200 kilometres

Figure 45-1. Location of James Bay Lowland OTH indicator mineral survey.

the +10 mesh (+2 mm) size fraction. The entire –10 mesh size fraction is then passed across a shaker table twice to produce a rough heavy mineral concentrate. Samples in which a pre-determined number of gold grains are seen during shaker table processing have the heavy mineral (table) concentrate refined by hand or mechanical panning to concentrate all contained gold grains and associated pathfinder minerals. Following the panning (if required), the tabled heavy mineral separates undergo a heavy liquid separation. The specific gravity of the heavy liquid used during this procedure is 3.2 g/cm^3. After heavy liquid separation the magnetic minerals are separated using an automagnet. The paramagnetic fractions (weakly, moderately and strongly paramagnetic) and non-paramagnetic fractions are isolated using appropriate methodology. The final heavy mineral concentrate (HMC) is sieved to obtain 4 size fractions (< 0.25, 0.25 to 0.5, 0.5 to 1.0 and 1.0 to 2.0 mm), each of which is weighed and placed in vials.

Indicator mineral picking is then performed on the 0.25 to 0.5, 0.5 to 1.0 and 1.0 to 2.0 mm size fractions. A scanning electron microscope is used to confirm/check any questionable picked grains. The indicator minerals are then submitted to the Geoscience Laboratories for microprobe analysis.

QUALITY CONTROL/QUALITY ASSURANCE PROCEDURES

Quality control/quality assurance (QC/QA) in the field is crucial to a successful indicator mineral sampling program. Quality control involves: 1) proactive measures at the time of sample collection; and 2) quality assurance procedures at all stages of the sample collection/handling/analysis process. To ensure that OGS protocols were adhered to, a rigid quality assurance program was instituted to ensure the integrity of samples collected and data acquired. The program involves 5 components:

1. A mandatory information and training session for the contractor prior to the commencement of field work. Follow-up information sessions and/or field visits by staff were done to ensure all aspects of sample protocols and requirements were understood;
2. The collection of method (field) duplicates. This procedure is intended to provide a fair determination of the contractor's performance with respect to sample collection and handling techniques and recording of sample site locations. Field duplicates were sequenced-in with the regular samples following fieldwork;
3. Sieve tests to determine if submitted samples contain sufficient sand sized inorganic material as per OGS specifications;
4. The use of bulk sample weight and table feed weight criteria to ensure performance requirements have been met by the sample collection Contractor;
5. The application of penalties proportional to the degree of non-performance of OGS protocols and procedures.

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Morris, T.F. and Kaszycki, C.A. 1997. Prospector's guide to drift prospecting for diamonds, northern Ontario; Ontario Geological Survey, Miscellaneous Paper 167, 63p.

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46. Ontario Mineral Exploration Technologies (OMET) Program

E. Debicki[1] and J.A. Fyon[2]

[1]Mineral Exploration Research Centre, Laurentian University, Sudbury
[2]Precambrian Geoscience Section, Ontario Geological Survey

WHAT IS OMET?

On September 11, 2000, the then-Minister of Northern Development and Mines (MNDM), Tim Hudak, announced the Ontario Mineral Exploration Technologies (OMET) Program.

The OMET Program is a four-year, $8 million Ontario MNDM initiative that will focus on developing and testing innovative mineral exploration technologies and methods that promise to enhance the efficiency of exploration firms in high potential geological areas of Ontario.

If these technologies and methods are proven effective, they can be exported around the world.

As referenced in the Spring 2000 Budget, the OMET Program will increase Ontario's attractiveness to mining and mineral exploration firms by funding high-potential research projects. By encouraging made-in-Ontario solutions to Ontario's mineral exploration challenges, the initiative will reaffirm the Ontario government's commitment to the mining industry and consolidate the province's position at the vanguard on mining jurisdictions.

GOAL AND OBJECTIVE

The goal of the OMET Program is to lever the Government of Ontario's investment in innovative, collaborative, multidisciplinary technology and methods research projects to provide solutions to technical problems facing the mineral exploration industry in Ontario.

The objective of the OMET Program is to develop new technologies and methods to help find the next generation of Ontario's mineral deposits in areas of complex geology.

FUNDING AND PROGRAM DURATION

The OMET Program is a four-year, $8 million program that was initiated on April 17, 2001, with the official signing ceremony between the Minister of Northern Development and Mines, Dan Newman, and the then-president of Laurentian University, Dr. Jean Watters.

The four-year funding plan is $500 000 for 2000 to 2001, and $2.5 million for each of the subsequent three years (2001 to 2002, 2002 to 2003 and 2003 to 2004). The OMET Program will conclude on March 31, 2004.

ADMINISTRATIVE PARTNERSHIP

The OMET Program is an administrative partnership between

- Ontario Geological Survey (OGS) of the Ministry of Northern Development and Mines
- Mineral Exploration Research Centre (MERC) of Laurentian University

MERC will manage and administer the OMET Program on behalf of MNDM.

PRIORITY AREAS FOR RESEARCH

Three priority areas of research are envisioned for the OMET Program:

1. Best techniques to find mineral resources in bedrock beneath conductive or thick overburden and/or bedrock. These conditions are common throughout Ontario.
2. Best methods to "see" through the Paleozoic rocks to explore for mineral resources, including diamonds, in the underlying Precambrian rocks of the Hudson Bay and James Bay lowlands.
3. Effective ways to utilize Ontario's Quaternary geology to explore for mineral resources in the bedrock.

Three types of projects will be considered:

- "*Develop a concept*" project. The concept is at the theoretical or idea stage, or the concept requires validation under Ontario's complex geological conditions.
- "*Prove a concept*" project. The technology is proven to work at the desktop level or in the lab, or a method or instrumentation will be derived to work under specific Ontario field conditions.
- "*Demonstration*" project. The technology is proven in the field or by another industry, and the research will show that the technique is applicable to Ontario's mineral exploration industry.

Other projects of merit will also be considered. Preference will be given to collaborative proposals with potential to attract matching funds. High-cost, high-risk "technology-build" types of projects are discouraged.

OMET ORGANIZATION CHART

Figure 46.1 provides an outline of the OMET organization. Proposals submitted to the OMET Program Office will be reviewed by the OMET Program Coordinator to ensure the proposal is complete. The proposal is then forwarded to the members of the Expert Technical Advisory Committee (ETAC) who will conduct a peer review. The ETAC Chair and the OMET Program Coordinator recommend proposals to the OMET Management Board for acceptance or rejection.

Ontario Mineral Exploration Technologies (OMET) Program

Organization Chart

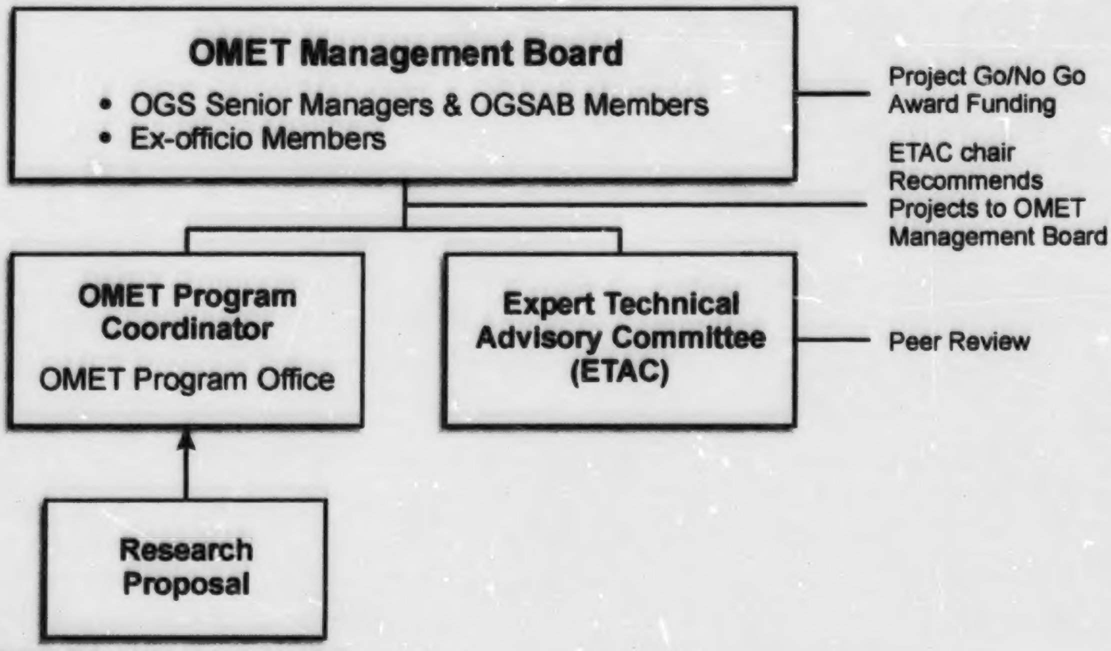
OMET Management Board
• OGS Senior Managers & OGSAB Members
• Ex-officio Members
Project Go/No Go Award Funding
ETAC chair Recommends Projects to OMET Management Board
OMET Program Coordinator
OMET Program Office
Expert Technical Advisory Committee (ETAC)
Peer Review
Research Proposal

Figure 46.1. OMET Organization Chart.

OMET Management Board

The OMET Management Board will review the recommendations of the Expert Technical Advisory Committee (ETAC), and make a final decision to approve a proposal, and the level of funding for the proposal.

The OMET Management Board is made up of five voting members, and two non-voting ex-officio members.

- Voting Members (5)
  - Ontario Geological Survey (OGS) Senior Managers
    - Cam Baker – Sedimentary Geoscience Section
    - Andy Fyon – Precambrian Geoscience Section
    - Hial Newsome – Resident Geologists Program
  - Ontario Geological Survey Advisory Board (OGSAB) Members
    - Industry Representative: Chair, OGSAB (individual to be announced when new OGSAB Chair appointed for next term)
    - University Representative: Greg Finn, Earth Sciences, Brock University (Chair of the Council of University Departments of Geoscience in Ontario (CUDGO))

- Non-voting Members (2) – Ex-Officio
    - Ed Debicki – OMET Program Coordinator
    - John Gingerich – Chair of the ETAC

Expert Technical Advisory Committee

The Expert Technical Advisory Committee (ETAC) conducts peer reviews of the proposal submissions, and recommends to the OMET Management Board whether a proposal should be accepted or rejected. The ETAC is composed of 10 members and the Committee Chair.

The ETAC members provide expertise in

- Geology
- Geochemistry
- Geophysics
- Quaternary and overburden
- GIS, computer, geomatics, and data processing/imaging

The Chair of the ETAC is

- John Gingerich, Director, Research and Technical Innovation,
  Noranda Inc., Toronto, ON

The ten members of the ETAC are

- Cameron Bowie, Area Geologist, Geomatics Specialist,
  Inco Technical Services Limited, Copper Cliff, ON
- William B. Coker, Chief Geochemist, Global Geoscience Team, Minerals Exploration,
  BHP Billiton World Exploration Inc., Vancouver, BC
- Andrew Cooper, Senior Geologist,
  Jagger Hims Limited, Newmarket, ON
- Chris Gleeson, Geochemical Consultant,
  C.F. Gleeson & Associates Ltd., Iroquois, ON
- Scott Hogg, President,
  Scott Hogg & Associates Ltd., Toronto, ON
- Alan King, Manager, Geophysics,
  Inco Technical Services Limited, Copper Cliff, ON
- Tom Lane, Geological Consultant,
  Toronto, ON
- Ian MacLeod, Chairman,
  Geosoft Inc., Toronto, ON
- Ed Pattison, Geological Consultant,
  Edward Pattison & Associates, Naughton, ON
- L. Harvey Thorleifson, Research Geologist,
  Geological Survey of Canada, Ottawa, ON

SUBMISSION OF PROPOSALS

The OMET Program is open to any individual researcher, collaborative team of researchers, or any organization.

Proposals can be submitted at any time during the 2001 to 2002 fiscal year (April 1, 2001 to March 31, 2002). Proposals for the 2002 to 2003 fiscal year, and the 2003 to 2004 fiscal year will be accepted anytime after April 1, 2002, and April 1, 2003, respectively.

The submission of proposals is a two-stage process. The proponent can follow the two-stage submission process (Stage 1 followed by Stage 2), or go directly to Stage 2:

- Stage 1: OMET Letter of Intent Application Form
- Stage 2: OMET Project Application Form

The OMET Program Guidelines and Application Guidelines, along with the application forms can be found on the OMET web site at:

  - www.OMET.laurentian.ca

- Completed application forms can be submitted electronically to the OMET Program Office e-mail address at
  - OMET@nickel.laurentian.ca

Information about the OMET Program or assistance in completing the application form can be obtained from the OMET Program Office by contacting the OMET Program Coordinator or the OMET Administrative Assistant:

- OMET Program Office
  Ontario Mineral Exploration Technologies (OMET) Program
  Mineral Exploration Research Centre (MERC)
  Willet Green Miller Centre
  B8 – 933 Ramsey Lake Road
  Sudbury, ON P3E 6B5
  Tel. (705) 675-1151 Ext. 2366
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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
LENGTH					
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
AREA					
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.